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The State Of The Art - 1986

Volume I

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By

Melville Shipping Ltd.
Ottawa, Ontario

In Association with

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Canarctic Shipping Company Limted

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17. Abstract

This report presents the results of a review of Arctic ship technology. The objective of this review was to document the present state of the art in this field to provide ship designers and operators with a reference manual offering an up-to-date view of how the technology has developed over the last several decades.

A thorough literature search was conducted to identify relevant publications, technical reports and papers. The literature search is documented in the bibliography and the data sheets which together make up Volume II. The data obtained from this literature search was used as the basis for the state of the art review presented in Volume I. The review is organized into the following subject areas: a) existing icebreaking ships; b) environment: ice, sea and meteorological conditions; c) ship operation: safety, navigation and communications; and, d) ship design: ship structure, hull, propulsion equipment, general outfit and auxiliary systems. The technology review is used, together with the results of a study on future Arctic shipping systems, to develop a programme of recommended research designed to address identified deficiencies.

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17. Résumé

Ce rapport présente les résultats du tour d'horizon sur la technologie des navires de cote arctique, dont l'objectif a été de mettre en évidence les connaissances acquises dans ce domaine et de fournir aux concepteurs et aux armateurs un ouvrage de référence sur l'évolution des techniques au cours des dernières décennies.

Une recherche documentaire exhaustive a été faite en vue de répertorier les ouvrages, rapports et mémoires traitant de ce domaine. Le résultat de cette recherche est repris dans la bibliographie et les feuillets de renseignements formant le tome 2. Le contenu des ouvrages cités dans la bibliographie a servi de base au tour d'horizon présenté dans le tome 1. Les résultats sont organisés comme suit: a) brise-glace actuels; b) environnement glaciel, marin et météorologique; c) exploitation: sécurité, navigation et communications; d) conception: structures, coques, appareil propulsif, aménagements et systèmes auxiliaires. Ce tour d'horizon ainsi que le résultat de l'étude sur les systèmes de navigation arctique du futur doivent servir à l'élaboration du programme des recherches à lancer dans le but de combler les lacunes mises en évidence.

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1. INTRODUCTION

This review of the state-of-the-art of Arctic ship technology was commissioned in 1985 by Transport Canada's Transportation Development Centre (TDC) and has been co-sponsored by Canarctic Shipping Company Limited (Canarctic) and Melville Shipping Ltd. (Melville). The project has been the responsibility of Melville, with assistance from Canarctic in the areas of Environment and Operations, and from Arctec Canada Limited (Arctec) in the areas of Structures and Performance Prediction.

The review is directed at those ship designers, ship operators and regulators who are involved in the planning and development of Arctic shipping projects. A separate report entitled "Probable Arctic Shipping Scenarios" identifies the shipping projects which may occur in the Arctic. This report had the input of ship owners and operators, Government departments and resource owners, and summarized the probable development plans to the year 2000. This provided guidelines for the technology review in terms of geographic locations, length of season, size of vessels, vessel capability and operational considerations.

Synthesizing the large information base of Arctic ship technology into a one volume review must result in an incomplete description of some facets. For this reason the review contains only the information which is judged by the authors to be of particular relevance or to add to the overall understanding of the issues being discussed.

A literature search was completed to establish the breadth of information available. The information obtained during this search is presented in this review in three ways.

a) A bibliography has been prepared and is included in Volume Two. This bibliography contains a list of the literature which has some relevance in the development of Arctic ship technology. The list numbers about 750 titles.

b) A set of bibliographic data sheets have been prepared and included in Volume Two. These sheets contain a brief abstract of items of literature which have been referenced in the main text or are considered to be of sufficient interest. Not all items in the bibliography have a bibliography information sheet since not all items contribute to our present understanding of the state-of-the-art.

c) Those items of literature judged to be important when describing the state-of-the-art are referenced in the main text. These references are intended to highlight for the reader that the contributions of those authors are important and have been used to illustrate particular points, and that the literature can/should be obtained for more in-depth analysis.

The main text presents a review of Arctic ship technology covering, in separate sections, a) the chacteristics of existing icebreaking ships, b) the Arctic environment, c) the major areas of concern for ship operations, ie. safety, navigation and communications and d) the areas of importance to ship design: ie. structures, hull design and performance, propulsion and general outfit and auxiliary systems. The text has been prepared in a manner designed to inform the reader of the authors' opinion of the state-of-the-art in each area of importance. Where statements are made which require support, references are provided.

Of importance is the identification of deficiencies which must be eliminated to achieve an acceptable level of understanding of ship design and operations for Arctic ships. These deficiencies are identified in each section of the review and brought together as a proposed research programme in Section 7. This programme is intended to be a guide to designers, operators and regulators on the work which is yet to be completed before confidence can be achieved in the design and operation of these future vessels.

2. EXISTING ICEBREAKING SHIPS

2.1 Introduction

A review of icebreaking technology can use the ships which have been built as a base against which innovative designs or operating proposals may be compared and assessed. The danger is that, by accepting too rigidly the status quo, innovation will be discouraged. Ideally, innovation should spring from a full understanding of past experience.

While icebreakers and icebreaking cargo ships have a long history, the Wind Class vessels, which were built in the mid 1940's, are used here as a starting point. While interesting developments did occur before that time, few are having an impact on today's understanding of the technology.

Data has been compiled for icebreakers and icebreaking cargo ships from the following countries:

- Argentina
- Canada
- Denmark
- Finland
- Japan
- Sweden
- United Kingdom
- U.S.S.R.
- U.S.A.
- West Germany

The available data is compiled for each ship in Tables 2.1.1 to 2.1.10. In many cases, due to the lack of published information, complete data on these vessels is not available. However, notwithstanding these deficiencies, the database is substantial. An analysis has been completed to extract information or relationships which may give some insight to the ship designer. Many of these relationships are discussed in later sections; some are of general interest and relate to the overall characteristics of icebreaking ships; these are discussed in this section.

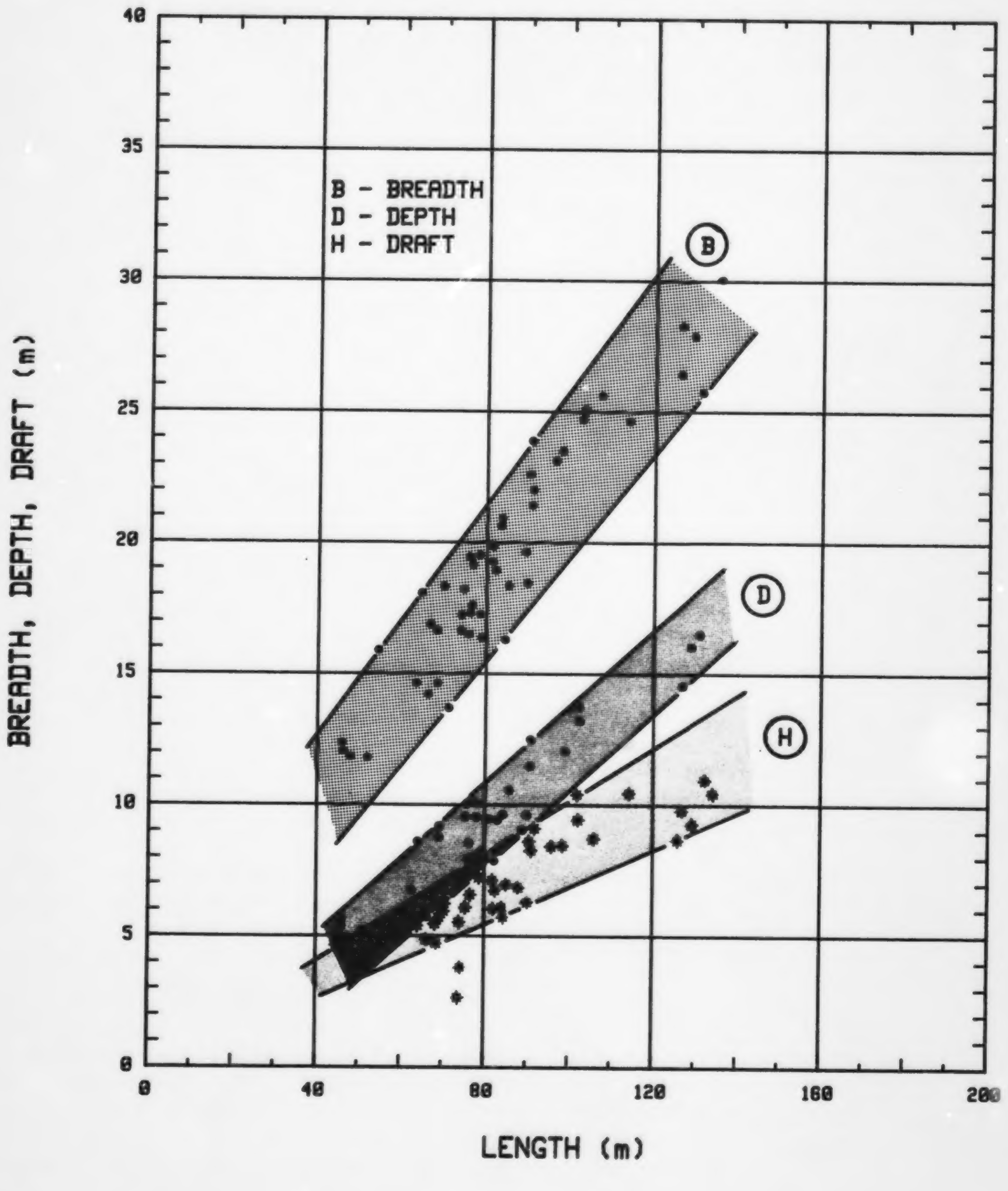
The data presented in this section should only be taken as an illustration of what has already been constructed, not as limits to the present design, construction or operational capability.

2.2 Dimensions

The main dimensions of each icebreaker are plotted in Figure 2.2.1. The figure shows breadth, depth, and draft against length. The relationships are seen to be quite linear but with ranges which are dependent on a number of influences.

FIGURE 2.2.1

ICEBREAKER DIMENSIONS



Note : Cargo ships are not included

TABLES 2.1.1 TO 2.1.10

GENERAL INFORMATION ON ICEBREAKING SHIPS

(Note: ND Means That No Data Is Available)

TABLE 2.1.1

INFORMATION ON ARGENTINE ICEBREAKING SHIPS

DATA	GENERAL SAN MARTIN	ALMIRANTE IRAZAR
VESSEL TYPE	Icebreaker	Icebreaker
ARCTIC CLASS OR EQUIVALENT	ND	ND
YEAR(S) OF CONSTRUCTION	1954	1978
DIMENSIONS		
- LBP (m)	76.87	ND
- B (m)	18.96	ND
- D (m)	8.63	ND
- H (m)	6.89	ND
- Displacement (tonnes)	5,301	14,900
FORM VARIABLES		
- Stem Angle (deg)	28	22
- Forward Block Coefficient	ND	ND
- Kashteljan coefficient	ND	ND
- Shimanski Coefficient	ND	ND
- Bow Type	ND	ND
PROPULSION		
- Total Power (MW)	5.33	12.15
- Bollard Pull (tonnes)	61.2	140
- # Shafts	2	2
- Power per Shaft (MW)	2.67	6.08
- Machinery	Diesel DC-DC -	Diesel AC-DC -
- Propeller(s)	2 x FP	2 x FP
. Diameter (m)	ND	ND
. # blades	ND	ND
. Nozzle(s)	No	No
PERFORMANCE		
- Open water (knots)	16	ND
- In Ice	2kn in 0.7m	ND
- BP/B (tonnes/m)	3.07	ND

TABLE 2.1.2

INFORMATION ON CANADIAN ICEBREAKING SHIPS

LABRADOR	S.R. HUMPHREY GILBERT	JOHN A. MACDONALD	JOHN CABOT
Icebreaker	Icebreaker	Icebreaker	Icebreaking Cable Layer
ND	ND	ND	ND
1954	1959	1960	1965
77.9	68.9	88.39	84.1
18.9	14.69	21.34	18.29
11.57	6.40	12.53	10.42
9.3	4.98	8.57	6.74
6,490	3,048	9,160	5,318
30	25	34	ND
ND	ND	ND	ND
ND	ND	ND	ND
ND	ND	ND	ND
Straight Stem	ND	ND	ND
7.5	3.169	11.25	6.71
89	46	133	80
2	2	3	2
3.75	1.58	3.75	3.38
Diesel	Diesel	Diesel	Diesel
DC-DC	Direct Drive	DC-DC	DC-DC
-	-	-	-
2 x FP	2 X FP	3 x FP	2 x FP
4.57	3.51	4.10	3.96
4	4	4	4
No	No	No	No
16	13	15.5	15.0
2kn in 0.82m	2kn in 0.67m	2kn in 0.91m	2kn in 0.75m
4.71	3.13	6.23	4.37

TABLE 2.1.2 (con't)

INFORMATION ON CANADIAN ICEBREAKING SHIPS

DATA	NORMAN McLEOD ROGERS	LOUIS S. ST-LAURENT	ARCTIC (1978-86)
VESSEL	Icebreaker	Icebreaker	Cargo
ARCTIC CLASS OR EQUIVALENT	ND	ND	2
YEAR(S) OF CONSTRUCTION	1969	1969	1978
DIMENSIONS			
- LBP (m)	81.15	101.8	196.59
- B (m)	19.05	24.4	22.86
- D (m)	7.93	13.1	15.24
- H (m)	6.25	9.4	10.93
- Displacement (tonnes)	6,569	13,513	38,104
FORM VARIABLES			
- Stem Angle (deg)	62-26	32	30
- Forward Block Coefficien	0.69	0.543	0.515
- Kashteljan Coefficient	2.403	1.995	1.650
- Shimanski Coefficient	2.494	2.29	2.620
- Bow Type	ND	ND	White
PROPULSION			
- Total Power (MW)	8.95	17.9	11.08
- Bollard Pull (tonnes)	118	212	155
- # Shafts	2	3	1
- Power per Shaft (MW)	5	5.96	11.08
- Machinery	Diesel DC-DC -	Steam Turbines DC-DC -	Diesel Direct Drive -
- Propeller(s)	2 x FP	3 x FP	1 x CP
. Diameter (m)	3.66	4.57	5.23
. # Blades	4	4	4
. Nozzle(s)	No	No	Yes
PERFORMANCE			
- Open Water (knots)	15.0	17.75	16.5
- In Ice	2kn in 0.91m	1.0	2kn in 1.0m
- BP/B (tonnes/m)	6.19	8.69	6.79

TABLE 2.1.2 (con't)

INFORMATION ON CANADIAN ICEBREAKING SHIPS

ARCTIC (1986 -)	SIR JOHN FRANKLIN PIERRE RADISSON DES GROSEILLER	CANMAR KIGORIAK	ROBERT LEMEUR
Cargo	Icebreaker	Ice Management Supply Vessel	Ice Management Supply Vessel
4	3	3	3
1978	1978-84	1979	1982
206	87.94	79.34	73.0
22.86	19.37	17.25/18.25	18.0/19.0
15.24	ND	10.0	7.5
10.93	6.93	8.53	5.67
38,466	7,825	6,549	5,853
20	18	24	20
0.395	0.536	ND	ND
1.244	1.53	ND	ND
2.962	2.208	ND	ND
Melville	White	Spoon/Reamers	Spoon/Reamers
11.08	10.14	13.05	7.2
155	130	200	120 or 110
1	2	1	2
11.08	5.5	13.05	3.6
Diesel	Diesel	Diesel	Diesel
Direct Drive	AC-DC	Direct Drive	Direct Drive
-	-	-	-
1 x CP	2 x FP	1 x CP	2 x CP
5.23	4.12	5.3	3.0
4	4	4	4
Yes	No	Yes	Yes
17.25	13.5	18.6	13.5
2kn in 1.5m	2kn in 1.15m	2kn in 1.45m	2kn in 1.5m
6.79	6.71	10.96	6.31

TABLE 2.1.2 (con't)

INFORMATION ON CANADIAN ICEBREAKING SHIPS

DATA	ARCTIC NANOOK ARCTIC NUTSUKPOK	TERRY FOX KALVIK	IKALUK MISCAROO
VESSEL TYPE	Ice Management Supply Vessel	Ice Management Supply Vessel	Ice Management Supply Vessel
ARCTIC CLASS OR EQUIVALENT	2	4	4
YEAR(S) OF CONSTRUCTION	1982	1983	1983
DIMENSIONS			
- LBP (m)	44.2	75	75.5
- B (m)	12.2	17.5	17.22
- D (m)	5.3	10	9.7
- H (m)	4.1	8	7.5
- Displacement (tonnes)	ND	6,910	ND
FORM VARIABLES			
- Stem Angle (deg)	22	23	23
- Forward Block Coefficient	ND	ND	ND
- Kashteljan Coefficient	ND	ND	ND
- Shimanski Coefficient	ND	ND	ND
- Bow Type	Flat Family	ND	ND
PROPULSION			
- Total Power (MW)	4.83	17.3	11.2
- Bollard Pull (tonnes)	72	200	175
- # Shafts	2	2	2
- Power per Shaft (MW)	2.42	8.65	5.6
- Machinery	Diesel Direct Drive	Diesel Direct Dirve	Diesel Direct Drive
	-	-	-
- Propellers	2 x CP	2 x CP	2 x CP
. Diameter (m)	ND	4.8	3.75
. # Blades	4	4	4
. Nozzles(s)	Yes	No	Yes
PERFORMANCE			
- Open Water	15	14	ND
- In Ice	ND	7kn in 1.22m (82%)	3-4kn in 1.2m
- BP/B (tonnes/m)	ND	12	10.16

TABLE 2.1.2 (con't)

INFORMATION ON CANADIAN ICEBREAKING SHIPS

ARCTIC SHIKO SEAFORTH ATLANTIC	ARCTIC NANABUSH	ARCTIC IVIK	1100's GEO. R. PEARKES MARTHA L. BLACK
Ice Management Supply Vessel	Ice Management Supply Vessel	Ice Management Supply Vessel	Light Icebreakers
2	2	2	2
1984	1984	1985	1986
60.9	44.2	64.7	83
14.5	12.2	14.0	16.2
6.9	5.3	5.8	7.9
5.9	4.6	4.9	5.75
ND	ND	ND	5031
32	22	22	25
ND	ND	ND	ND
1.87	ND	ND	ND
2.70	ND	ND	ND
White	Flat Family	Flat Family	ND
9.18	5.4	5.4	5.25
129	80	81	57
2	2	2	2
4.59	2.7	2.7	2.63
Diesel	Diesel	Diesel	Diesel
Direct Drive	Direct Drive	Direct Drive	AC-FCC-AC
-	-	-	-
2 x CP	2 x CP	2 x CP	2 x FP
3.0	ND	ND	3.6
4	4	4	4
Yes	Yes	Yes	No
16	15	14.1	15.5
2kn in 1.05m	2kn in 0.9m	2kn in 0.9m	ND
8.9	6.56	5.79	3.55

TABLE 2.1.2 (con't)

INFORMATION ON CANADIAN ICEBREAKING SHIPS

DATA	EDWARD CORNWALLIS SIR WILFRED LAURIER	EARL GREY SAMUAL RISLEY
VESSEL TYPE	Light Icebreakers	Light Icebreaker
ARCTIC CLASS OR EQUIVALENT	2	2
YEAR(S) OF CONSTRUCTION	1986	1985-1986
DIMENSIONS		
- LBP (m)	78.4	69.73
- B (m)	16.2	13.7
- D (m)	7.75	6.7
- H (m)	6.03	5.2
- Displacement (tonnes)	4966	2930
FORM VARIABLES		
- Stem Angle (deg)	25	25
- Forward Block Coefficient	ND	ND
- Kashteljan Coefficient	ND	ND
- Shimanski Coefficient	ND	ND
- Bow Type	ND	ND
PROPULSION		
- Total Power (MW)	5.25	6.5
- Bollard Pull (tonnes)	57	5.19
- # Shafts	2	2
- Power per Shaft (MW)	2.63	3.25
- Machinery	Diesel AC-FFC-AC -	Diesel Direct Drive -
- Propeller(s)	2 x FP	2 x FP
. Diameter (m)	3.6	4
. # Blades	4	3.0
. Nozzle(s)	No	No
PERFORMANCE		
- Open Water (knots)	15.5	14.3
- In Ice	ND	ND
- BP/B (tonnes/m)	3.55	5.19

TABLE 2.1.3

INFORMATION ON DANISH ICEBREAKING SHIPS

DANBJORN ISBJORN	DAMSA DAN
Icebreaker	Cargo
ND	ND
1965	1973
67.97	124.97
16.99	18.14
8.99	11.25
6.0	7.41
3,744	12,091
ND	ND
ND	ND
ND	ND
ND	ND
ND	ND
7.88	6.75
91	78
2A + 2F	1
1.97	6.75
Diesel	Diesel
DC-DC	Direct Drive
-	-
4 x FP	1 x CP
ND	ND
ND	ND
No	No
17	17.5
2kn in 1.0m	2kn in 0.67m
5.36	4.28

TABLE 2.1.4

INFORMATION ON JAPANESE ICEBREAKING SHIPS

DATA	FUJI	SOYA	SHIRASE
VESSEL TYPE	Icebreaker	Icebreaking Patrol Vessel	Icebreaker
ARCTIC CLASS OR EQUIVALENT	ND	ND	4 (Exp.)
YEAR(S) OF CONSTRUCTION	1965	1978	1982
DIMENSIONS			
- LBP (m)	90	94	127
- B (m)	22	15.6	28
- D (m)	11.8	8.0	14.5
- H (m)	8.98	5.47	9.75
- Displacement (tonnes)	9,120	4,000	18,600
FORM VARIABLES			
- Stem Angle (deg)	30	ND	21
- Forward Block Coefficient	ND	ND	ND
- Kashteljan Coefficient	ND	ND	ND
- Shimanski Coefficient	ND	ND	ND
- Bow Type	ND	ND	ND
PROPULSION			
- Total Power (MW)	8	11.7	22.5
- Bollard Pull (tonnes)	92	134	259
- # Shafts	2	ND	3
- Power per Shaft (MW)	4	ND	7.5
- Machinery	Diesel DC-DC -	ND - -	Diesel AC-DC -
- Propeller(s)	2 x FP	ND	3 x FP
. Diameter (m)	4.9	ND	4.9
. # Blades	4	ND	4
. Nozzle(s)	No	ND	No
PERFORMANCE			
- Open Water (knots)	17	ND	19
- In Ice	2kn in 0.8m	2kn in 1.2m	3kn in 1.5m
- BVP/B (tonnes/m)	4.18	8.62	9.23

TABLE 2.1.5

INFORMATION ON FINNISH ICEBREAKING SHIPS

VOIMA	KARHU MURTAJA SEMPO	TARMO VARMO APU	HANSE
Icebreaker	Icebreaker	Icebreaker	Icebreaker
ND	ND	ND	ND
1953 (1978)	1957/1958/1960	1963/1968/1976	1966
80.77	68.28	82	74.13
18.72	16.69	21.17	17.37
9.57	8.81	9.63	ND
6.74	5.79	6.19	6.1
4,486	3,424	5,944	3,759
27	25	24	ND
ND	ND	ND	ND
ND	ND	ND	ND
ND	ND	ND	ND
ND	ND	ND	ND
7.88 (10.5)	5.63	8	5.63
91	65	115	65
2A + 2F	2A + 2F	2A + 2F	2A + 2F
1.97	1.41	2.0	1.41
Diesel	Diesel	Diesel	Diesel
DC-DC	DC-DC	DC-DC	DC-DC
-	-	-	-
4 x FP	4 X FP	4 x FP	4 x FP
ND	ND	ND	ND
4	4	4	4
No	No	No	No
16.5	16	17	16
2kn in 0.82m	2kn in 0.7m	2kn in 0.85m	2kn in 0.72m
4.84	3.88	4.34	3.74
			3.74

TABLE 2.1.5 (con't)

INFORMATION ON FINNISH ICEBREAKING SHIPS

DATA	FINLANDIA	FINN CARRIER	URHO SISU
VESSEL TYPE	Passenger Ro-Ro	Cargo	Icebreaker
ARCTIC CLASS OR EQUIVALENT	ND	ND	ND
YEAR(S) OF CONSTRUCTION	1967	ND	1974-1976
DIMENSIONS			
- LBP (m)	133.96	129.94	96.01
- B (m)	20.0	24.57	23.5
- D (m)	ND	17.34	ND
- H (m)	5.58	5.67	8.3
- Displacement (tonnes)	6,706	10,567	7,925
FORM VARIABLES			
- Stem Angle (deg)	ND	ND	20
- Forward Block Coefficient	ND	ND	ND
- Kashteljan Coefficient	ND	1.36	ND
- Shimanski Coefficient	ND	4.38	ND
- Bow Type	ND	ND	ND
PROPULSION			
- Total Power (MW)	12.3	8.37	16.2
- Bollard Pull (tonnes)	141	96	190
- # Shafts	2	2	2A + 2F
- Power per Shaft (MW)	6.15	4.19	4.05
- Machinery	Diesel Direct Drive	Diesel Direct Drive	Diesel DC-DC
- Propeller(s)	-	-	-
. Diameter (m)	2 x CP	2 x FP	4 x FP
. # blades	ND	ND	ND
. Nozzle(s)	4	4	4
	No	No	No
PERFORMANCE			
- Open Water (knots)	23	17	17
- In Ice	2kn in 1.0m	ND	2kn in 1.56m
-BP/B (tonnes/m)	7.07	3.92	7.92

TABLE 2.1.5 (con't)

INFORMATION ON FINNISH ICEBREAKING SHIPS

LUNNI SOTKA TIIRA UIKKU	OTSO (CLASS OF 2)
Oil Tankers	Icebreaker
1A Super	ND
1976/76/77/77	1986
150.0	90.0
21.50	23.5
12.0	ND
9.5	8.0
ND	ND
ND	ND
ND	ND
ND	ND
ND	ND
ND	ND
11.48	15
132	172
1	2
11.48	7.5
Diesel	Diesel
Direct Drive	AC-FFC-AC
-	-
1 x CP	2 x FP
5.45	-
4	-
No	No
14.5	18.5
2kn in 1.0m	ND
6.14	7.12

TABLE 2.1.6

INFORMATION ON SWEDISH ICEBREAKING SHIPS

DATA	ODEN	TOR NJORD	SVEA DROTT
VESSEL TYPE	Icebreaker	Icebreaker	Ferry
ARCTIC CLASS OR EQUIVALENT	ND	ND	ND
YEAR(S) OF CONSTRUCTION	1957	1964/1969	1966
DIMENSIONS			
- LBP (m)	78	27.51	89.99
- B (m)	19.43	21.18	10.36
- D (m)	9.51	9.51	ND
- H (m)	7.01	6.49	ND
- Displacement (tonnes)	5,030	5,357	ND
FORM VARIABLES			
- Stem Angle (deg)	ND	ND	ND
- Forward Block Coefficient	ND	ND	ND
- Kashteljan Coefficient	ND	ND	ND
- Shimanski Coefficient	ND	ND	ND
- Bow Type	ND	ND	ND
PROPULSION			
- Total Power (MW)	7.88	8	8
- Bollard Pull (tonnes)	91	92	92
- # Shafts	2A + 2F	2A + 2F	2
- Power per Shaft (MW)	1.97	2	4
- Machinery	Diesel DC-DC	Diesel DC-DC	Diesel Direct Drive
	-	-	-
- Propeller(s)	4 x FP	4 x FP	2 x CP
. Diameter (m)	ND	ND	ND
. # blades	ND	ND	ND
. Nozzle(s)	No	No	No
PERFORMANCE			
- Open Water (knots)	17	18	20
- In Ice	2kn in 0.82m	2kn in 0.85m	2kn in 1.1m
- BP/B (tonnes/m)	4.68	4.34	8.88

TABLE 2.1.6 (con't)

INFORMATION ON SWEDISH ICEBREAKING SHIPS

YMER ATLE FREJ
Icebreaker
ND
1974/1975
96.01
23.47
12.1
8.3
7,900
20
ND
ND
ND
Straight Stem
16.5
190
2A + 2F
4.13
Diesel
DC-DC
-
4 x FP
ND
ND
No
17
2kn in 1.1m
8.1

TABLE 2.1.7

INFORMATION ON U.K. ICEBREAKING SHIPS

DATA	BRANSFIELD	POLAR SHORE
VESSEL TYPE	Icebreaker	Icebreaking Supply Vessel
ARCTIC CLASS OR EQUIVALENT	ND	ND
YEAR(S) OF CONSTRUCTION	1971	1973
DIMENSIONS		
- LBP (m)	89.98	51.06
- B (m)	18.29	11.77
- D (m)	9.51	5.09
- H (m)	6.21	4.33
- Displacement (tonnes)	7,011	ND
FORM VARIABLES		
- Stem Angle (deg)	ND	ND
- Forward Block Coefficient	ND	ND
- Kashteljan Coefficient	ND	ND
- Shimanski Coefficient	ND	ND
- Bow Type	ND	ND
PROPULSION		
- Total Power (MW)	3.75	3.96
- Bollard Pull (tonnes)	43	57
- # Shafts	1	2
- Power per Shaft (MW)	3.75	1.98
- Machinery	Diesel DC-DC -	Diesel Direct Drive -
- Propeller(s)	1 x CP	2 x CP
. Diameter (m)	ND	ND
. # blades	ND	ND
. Nozzle(s)	No	Yes
PERFORMANCE		
- Open Water (knots)	13.5	13.75
- In Ice	2kn in 0.52m	2kn in 0.76m
- BP/B (tonnes/m)	2.36	4.83

TABLE 2.1.8

INFORMATION ON U.S.A. ICEBREAKING SHIPS

WEST WIND NORTH WIND BURTON ISLAND	MACKINAW	GLACIER	POLAR STAR POLAR SEA
Icebreaker	Icebreaker	Icebreaker	Icebreaker
ND	ND	ND	ND
1943/45/46	1945	1955	1973/1976
76.2	85.35	90	107.29
19.36	22.56	22.56	25.45
ND	ND	[illegible].84	ND
ND	ND	[illegible]	8.54
6,515	5,252	8,[illegible]49	12,000
30	29	ND	15/28
ND	ND	ND	0.455
1.65	1.52	1.49	1.39
2.78	2.72	3.03	2.95
ND	ND	ND	White
7.5	7.5	15.75	45
86	90	181	517
2	2A + 1F	2	3
3.75	2.5	7.88	15
Diesel	Diesel	Diesel	GT Direct Drive
DC-DC	DC-DC	DC-DC	or Diesel AC-DC
-	-	-	-
2 x FP	3 x FP	2 x FP	3 x CP
5.18	ND	5.5	4.88
3	ND	3	4
No	No	No	No
16	18.7	17.6	17
2kn in 0.82m	2kn in 0.82m	ND	3kn in 1.83m
4.45	3.99	8.02	20.31

TABLE 2.1.8 (con't)

INFORMATION ON U.S.A. ICEBREAKING SHIPS

DATA	KATMAI BAY
VESSEL TYPE	Icebreaker
ARCTIC CLASS OR EQUIVALENT	ND
YEAR(S) OF CONSTRUCTION	1978
DIMENSIONS	
- LBP (m)	ND
- B (m)	11.4
- D (m)	ND
- H (m)	3.7
- Displacement (tonnes)	660
FORM VARIABLES	
- Stem Angle (deg)	28
- Forward Block Coefficient	ND
- Kashteljan Coefficient	ND
- Shimanski Coefficient	ND
- Bow Type	White
PROPULSION	
- Total Power (MW)	1.864
- Bollard Pull (tonnes)	22
- # Shafts	1
- Power per Shaft (MW)	1.864
- Machinery	Diesel DC-DC -
- Propeller(s)	1 x FP
. Diameter (m)	ND
. # Blades	ND
. Nozzles (s)	No
PERFORMANCE	
- Open Water (knots)	14.7
- In Ice	5.5kn in 0.41m
- BP/B (tonnes/m)	1.88

TABLE 2.1.9

INFORMATION ON U.S.S.R. ICEBREAKING SHIPS

KAPITAN BELOUSOV KAPITAN VERONIN KAPITAN MELEKHOV	LENIN	LENA CLASS (6)	MOSKVA LENINGRAD KIEV MURMANSK VLADIVOSTOK
Icebreaker	Icebreaker	Cargo	Icebreaker
ND	ND	ND	ND
1954/55/55	1957	1950(s)	1961/65/68/69
80.77	128.02	ND	112.41
19.89	27.59	18.90	24.48
9.51	16.12	11.20	11.49
7.01	9.205	8.27	10.52
5,300	16,000	ND	15,360
21	ND	ND	26.5
ND	ND	ND	0.598
ND	ND	ND	1.499
ND	ND	ND	3.311
ND	ND	ND	ND
7.88	32.4	6.15	16.5
91	379	71	190
2A + 2F	3	1	3
1.97	10.8	6.15	8.2/4.15
Diesel	3 x Nuclear Reactors	Diesel	Diesel
DC-DC	3 x Steam Turbines	DC-DC	DC-DC
-	DC-DC	-	-
4 x FP	3 x FP	1 x FP	3 x FP
3.5	5.64	ND	5.8/4.82
4	ND	ND	ND
No	No	No	No
16.5	18	15.4	18
2kn in 0.82m	2kn in 1.43m	2kn in 0.73m	2kn in 1.07m
4.69	13.74	3.74	7.75

TABLE 2.1.9 (con't)

INFORMATION ON U.S.S.R. ICEBREAKING SHIPS

DATA	VASILIY PRONCHISHCHEV CLASS (15)	AMGUEMA CLASS (13)	SEMYON DESHNOV IVAN MOSKVITIN
VESSEL TYPE	Icebreaker	Cargo	Icebreaker
ARCTIC CLASS OR EQUIVALENT	ND	ND	ND
YEAR(S) OF CONSTRUCTION	First In 1961	1962-1972	1971
DIMENSIONS			
- LBP (m)	62.0	ND	ND
- B (m)	18.04	18.90	ND
- D (m)	8.29	11.60	ND
- H (m)	5.49	9.10	ND
- Displacement (tonnes)	2,718	ND	15,000
FORM VARIABLES			
- Stem Angle (deg)	26	28	ND
- Forward Block Coefficient	ND	ND	ND
- Kashteljan Coefficient	ND	ND	ND
- Shimanski Coefficient	ND	ND	ND
- Bow Type	ND	ND	ND
PROPULSION			
- Total Power (MW)	4.05	5.4	22.5
- Bollard Pull (tonnes)	47	62	ND
- # Shafts	2A + 1F	1	ND
- Power per Shaft (MW)	1.33	5.4	ND
- Machinery	Diesel DC-DC -	Diesel DC-DC -	ND - -
- Propeller(s)	3 x FP	1 x FP	ND
. Diameter (m)	ND	ND	ND
. # Blades	ND	ND	ND
. Nozzle(s)	No	No	ND
PERFORMANCE			
- Open Water (knots)	14.5	15	ND
- In Ice	2kn in 0.61m	2kn in 0.70m	ND
- BP/B (tonnes/m)	2.58	3.28	ND

TABLE 2.1.9 (con't)

INFORMATION ON U.S.S.R. ICEBREAKING SHIPS

ERMAK ADMIRAL MAKAROV KRASIN	LEONID BRESHNEV SIBIR ROSSIYA	KAPITAN M. IZMAYLOR KAPITAN KASOLAPOV KAPITAN A. RADZHBOV	KAPITAN SOROKIN KAPITAN NIKOLAEV KAPITAN DRANITSYN KAPITAN KULEBNIKOV
Icebreaker	Icebreaker	Icebreaker	Icebreaker
ND	ND	ND	ND
1974	1975/77/85	1976	1977-78
129.97	133	54	125
25.6	29.99	16.0	26.5
16.7	ND	ND	ND
11	10.36	4.21	8.5
20,423	25,000	ND	14,900
26	24	ND	23
ND	ND	ND	ND
ND	ND	ND	ND
ND	ND	ND	ND
ND	ND	ND	ND
24	56	2.55	16.5
276	574	ND	ND
3	3	ND	3
8	16.65	ND	5.5
Diesel	Nuclear Reactors	Diesel	Diesel
DC-DC	Steam Turbines	AC-DC	AC-DC
-	AC-DC	-	-
3 x FP	3 x FP	ND	3 x FP
5.4	ND	ND	ND
ND	ND	ND	ND
No	No	ND	ND
20	25	ND	19
2kn in 1.53m	2kn in 1.77m	ND	ND
10.77	19.14	ND	ND

TABLE 2.1.9 (con't)

INFORMATION ON U.S.S.R. ICEBREAKING SHIPS

DATA	KAPITAN CHECHKIN KAPITAN PLAHIN KAPITAN CHADAEV KAPITAN KRUTOV KAPITAN BUKAEV KAPITAN ZARUBIN	STROPTIVY SPRAVED LIVY STAKHANOVETS SUVOROVETS SIBIRSKIY	MUDYUG MAGADAN DICKSON
VESSEL TYPE	Icebreaker	Icebreaker	Icebreaker
ARCTIC CLASS OR EQUIVALENT	ND	ND	ND
YEAR(S) OF CONSTRUCTION	1977-78	1979-80	1982-83
DIMENSIONS			
- LBP (m)	74	69	82
- B (m)	16.3	18.01	20.79
- D (m)	ND	ND	ND
- H (m)	3.26	6.01	
- Displacement (tonnes)	ND	ND	ND
FORM VARIABLES			
- Stem Angle (deg)	ND	ND	ND
- Forward Block Coefficient	ND	ND	ND
- Kashteljan Coefficient	ND	ND	ND
- Shimanski Coefficient	ND	ND	ND
- Bow Type	ND	ND	ND
PROPULSION			
- Total Power (MW)	3.37	5.7	9.56
- Bollard Pull (tonnes)	ND	ND	11.2
- # Shafts	ND	ND	2
- Power per Shaft (MW)	ND	ND	4.78
- Machinery	Diesel AC-DC	Diesel Direct Drive	Diesel Direct Drive
	-	-	-
- Propeller(s)	ND	ND	2 x CP
. Diameter (m)	ND	ND	4.00
. # Blades	ND	ND	4
. Nozzle(s)	ND	ND	No
PERFORMANCE			
- Open Water	ND	ND	ND
- In Ice	ND	ND	ND
- BP/B (tonnes/m)	ND	ND	5.39

TABLE 2.1.9 (con't)

INFORMATION ON U.S.S.R. ICEBREAKING SHIPS

SA-15 CLASS (19)	SERIES OF (7)	ALEKSEI KOSYGIN	SEVMORPUT	TAIMYR CLASS (2)
Cargo	Icebreaking	Lash Cargo	Lash Cargo	Icebreaker
ND	ND	ND	ND	ND
1982-86	1983-84	1984	1986	1988
164.0	73	ND	228.8	ND
24.5	16.61	ND	32.2	ND
15.2	ND	ND	18.3	ND
9.0	2.5	ND	10.7	ND
ND	ND	ND	61,000	ND
30	25	ND	30	ND
ND	ND	ND	ND	ND
ND	ND	ND	ND	ND
ND	ND	ND	ND	ND
ND	ND	ND	Straight Stem	ND
15.4	3.88	24.7	29.42	38.79
160	ND	ND	411	ND
1	2	2	1	3
15.4	1.94	12.35	29.42	12.93
Diesel	Diesel	2 x Slow Speed	Nuclear Reactor	Nuclear Reactor
Direct Drive	AC-DC	Diesel	Steam Turbine	Steam Turbine
-	-	Direct Drive	Direct Drive	AC-FFC-AC
1 x CP	ND	2 x FP	1 x CP	3 x FP
5.6	ND	5.6	8	ND
4	ND	ND	ND	ND
No	ND	No	Yes	No
17	ND	ND	20	ND
2kn in 1.2m	ND	ND	ND	ND
6.53	ND	ND	12.76	ND

TABLE 2.1.10

INFORMATION ON WEST GERMAN ICEBREAKING SHIPS

DATA	WERDERTOR	MAX WALDECK (Modified)	POLAR STERN
VESSEL TYPE	Icebreaking Supply Vessel	Icebreaker	Icebreaker
ARCTIC CLASS OR EQUIVALENT	ND	ND	ND
YEAR(S) OF CONSTRUCTION	ND	ND	1982
DIMENSIONS			
- LBP (m)	ND	46.58	102.2
- B (m)	14.0	11.90/13.10	25
- D (m)	ND	ND	13.6
- H (m)	ND	4.95	10.5
- Displacement (tonnes)	ND	1,295	15,000
FORM VARIABLES			
- Stem Angle (deg)	ND	16	24
- Forward Block Coefficient	ND	ND	ND
- Kashteljan Coefficient	ND	ND	ND
- Shimanski Coefficient	ND	ND	ND
- Bow Type	ND	Thyssen/WAAS	ND
PROPULSION			
- Total Power (MW)	7	2.38	14.68
- Bollard Pull (tonnes)	8.0	27	225
- # Shafts	ND	1	2
- Power per Shaft (MW)	ND	2,33	7.34
- Machinery	ND	ND	Diesel
	-	-	Direct Drive
	-	-	-
- Propeller(s)	ND	1 x FP	2 x CP
- Diameter (m)	ND	3.25	4.2
- # blades	ND	ND	4
- Nozzle(s)	ND	No	Yes
PERFORMANCE			
- Open Water (knots)	ND	ND	15.5
- Performance In Ice	2kn in 0.85m	2kn in 0.8m	2kn in 1.45m
	6.5 in 0.6m	(at 1.6 MW)	-
- BP/B (tonnes/m)	5.75	2.04	9

a) **Breadth (B)**

The mean L/B ratio varies, as a function of length, from 3.6 to 4.6 at lengths of 40 m and 140 m respectively. The range of breadth is created by the generally wider Finnish, Swedish and Soviet icebreakers and the generally narrower North American vessels. This may be explained by the convoy escort mode of operation common in the Baltic and Soviet Arctic.

b) **Depth (D)**

The mean L/D ratio varies, as a function of length, from 8.9 to 8.2 at lengths of 40 m to 140 m respectively. The range of depth values is created by the inclusion of ice management/offshore supply vessels in the data base. These ships have low freeboard and generally are designed to operate at a light draft. This combination of design features results in high L/D ratios compared to conventional icebreakers.

c) **Draft (H)**

The mean L/H ratio varies, as a function of length, from 11.4 to 12.2 at lengths of 40 m to 140 m respectively. The large range of values between the lengths of 70 m and 100 m is due to the inclusion of river icebreakers and Beaufort sea ice management vessels in the data base. Draft, like breadth, is usually defined by the ships operating requirements.

Despite the range of values of each variable, there are some trends apparent from the available information.

2.3 Hull Form

Hull forms have changed in several ways over the last 40 years. While few real trends can be detected, many design changes/innovations have been adopted, including;

- Straight stem
- Concave stem (White bow)
- Spoon bow with extended beam
- Spoon/chine bow
- Flat family bow
- Thyssen/Waas bow
- Melville bow

The progression of design improvements has led to a steadily increasing understanding of the hull form parameters which are important to ship resistance in ice. The more traditional way of assessing the shape of an icebreaking bow is to consider; the fineness (cb_f, block coefficient forward of the waterline shoulder), the stem angle, or the Kashteljan and Shimanski coefficients (which combine the flare and waterline entrance angles for the whole bow).

More recently, it has been recognised that it is not only the combination of flare and waterline angles which is important but also the location on the bow of these angles. The growing understanding of 'cusp patterns' and their importance to resistance has lead to attempts to design for particular cusp patterns.

The hull form information for several important ships has been extracted from the data in Tables 2.1.1 to 2.1.10 and is presented in Table 2.3.1. It can be seen that there is a weak trend towards reducing the stem angle, from about 30° for the earlier ships to about 20° for the later ships. The trend is not consistent but more modern icebreakers are being designed with lower stem angles. Similarly, the Kashteljan and Shimanski coefficients are changing with time to reflect the general reduction in stem angle. Since reducing stem angles result in a finer shape, the form coefficients will respond accordingly, ie. the Kashteljan coefficient will reduce and the Shimanski coefficient will increase.

Table 2.3.1
Hull Form Data for several Icebreakers

Ship	Date	Stem angle (deg.)	Kashteljan/Shimanski coefficients
WEST WIND	1943	30	1.65/2.78
VOIMA	1953	27	ND
JOHN A. MACDONALD	1960	34	ND
MOSKVA	1961	27	1.499/3.311
TARMO	1963	24	ND
FUJI	1965	30	ND
LOUIS S. ST-LAURENT	1969	32	1.995/2.29
POLAR STAR	1973	15	1.39/2.95
ERMAK	1974	26	ND
URHO	1974	20	ND
LEONID BRESHNEV	1975	24	ND
KAPITAN SOROKIN	1977	23	ND
PIERRE RADISSON	1978	18	1.53/2.208
CANMAR KIGORIAK	1979	24	ND
SHIRASE	1982	21	ND
TERRY FOX	1983	23	ND
Arctic (New Bow)	1986	20	1.244/2.962

* ND - No Data Available

The stern shape has experienced very few radical changes. Until the late 1970's, when the Beaufort Sea ice management ships began to introduce some unique features, the stern shape of icebreakers used the conventional open water ship configuration. This shape depends on the number of propellers and may have an ice horn to protect the rudder.

2.4 Power and Performance

The propulsion characteristics of these icebreakers or icebreaking cargo ships has yielded information on the relationship between power and ship size, and between power and performance in ice. Power versus breadth has been plotted in Figure 2.4.1 and bollard pull/breadth versus ice thickness in Figure 2.4.2

The power to breadth ratio has been used in the past as a measure of an icebreakers capability although the recent use of propeller nozzles distorts any comparisons which only use power. Bollard pull or total thrust is a more appropriate parameter since it includes the effect of any nozzle(s). The use of 'bollard pull divided by breadth' is a means of extracting the most important ship size parameter from the data set, thereby simplifying the comparisons of ship performance. In this way the difference in performance, which can be observed from the plotted data, can be attributed almost wholly to hull shape.

The power versus breadth data shown in Figure 2.4.1 demonstrate the trend of increase of power as a function of breadth. However, interpretation of these data is made difficult by the few ships with breadths larger than 25 m and by the different performance requirements of each vessel, ie. ships with the same breadth may be required to operate in ice of different thicknesses. However, with the exception of the TERRY FOX class, the POLAR class, and the Soviet Lash vessel there is a fairly well defined relationship between power and breadth for previously constructed vessels.

The bollard pull/breadth versus ice thickness data shown in Figure 2.4.2 has been produced from information on the known performance of these ships in ice. A speed of 2 knots was chosen to normalise the data since below this speed the vessels may not be able to sustain continuous progress.

Interpretation of these data is made uncertain by the lack of documented evidence on the performance of many ships. Notwithstanding this uncertainty, it is apparent that a fairly well defined relationship exists between bollard pull/breadth and the ice thickness which may be broken at 2 knots. The range shown in Figure 2.4.2 seems to represent the improvement which may be expected from improvements in hull shape. It can be seen that the most recent ships have more efficient hull forms.

It is also apparent that while the MAX WALDECK, ROBERT LEMEUR, and TERRY FOX, with non-traditional hull shapes, are very efficient, so too is the ARCTIC, recently modified with a high flare angle conventional bow. Perhaps the clearest indication of the importance of hull shape is the improvement obtained on the ARCTIC, increasing the ship's speed in 1.0 m of ice from 1.0 knot to 8.0 knots.

FIGURE 2.4.1

ICEBREAKER POWER VERSUS BREADTH

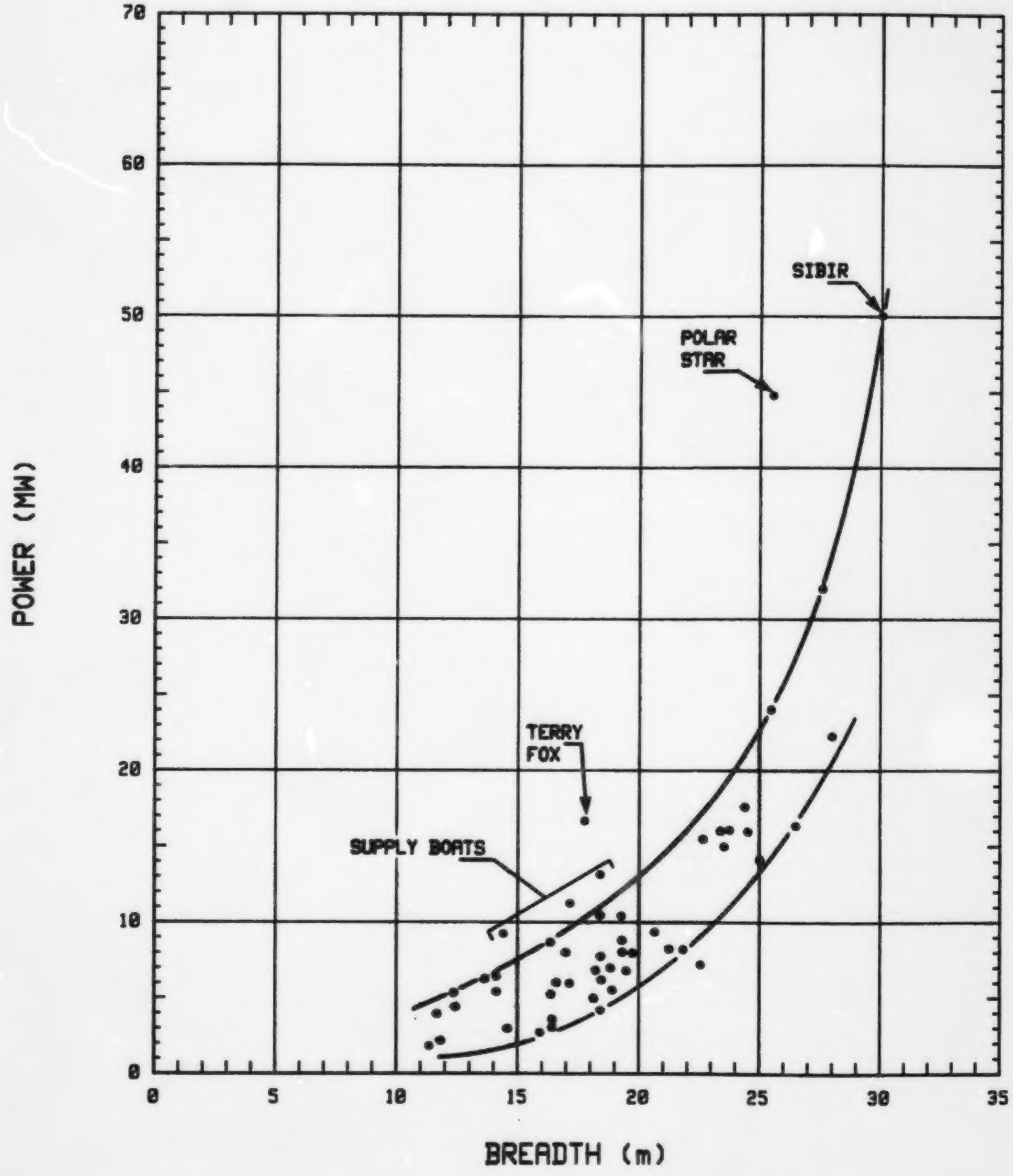
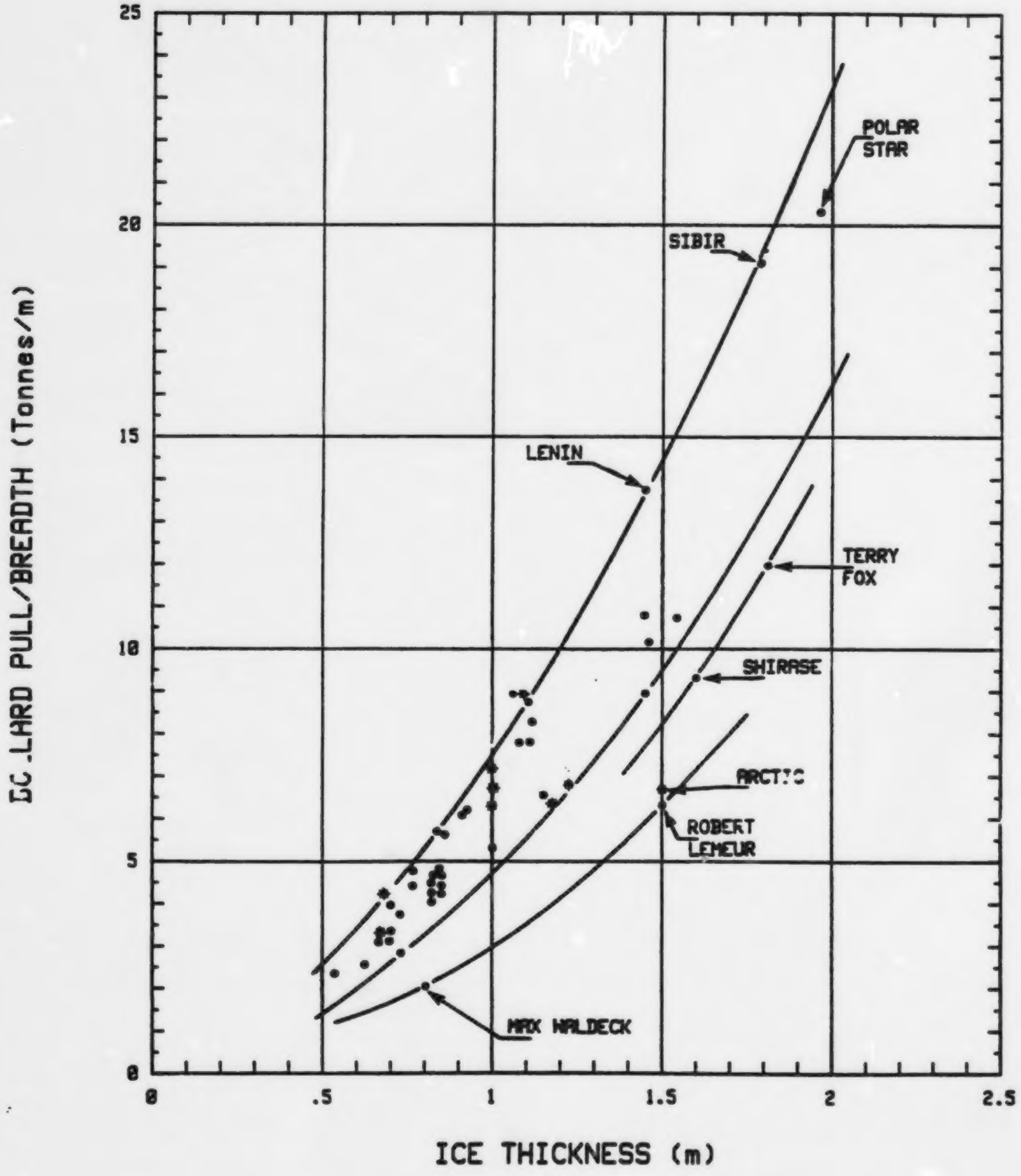


FIGURE 2.4.2

ICEBREAKING PERFORMANCE
BOLLARD PULL/BREADTH VERSUS ICE THICKNESS



Bollard pull is measured or calculated.
Data is adjusted for a 2 knot ship speed.

3. ENVIRONMENT

3.1 Introduction

The Arctic environment imposes limits on hull form and strength, powering requirements, bunkering and hotel arrangements; these limits are dictated by environmental design criteria. The severity of the Arctic environment varies seasonally (systematically) and also from year to year and this must be considered when selecting values to guide ship design.

In southern regions, environmental data have been collected on a dense network for a long period of time and design criteria can often be defined probabilistically. This is not the case in the Arctic regions, where the natural variability, sparse data collection network and short period of observations does not provide sufficient understanding of the phenomena to develop probabilistic criteria.

Described in this section are the formation, drift and deformation of sea ice; floating glacial ice; oceanographic characteristics such as currents and bathymetry; and important meteorological influences and climatic conditions. Values are also presented for a number of environmental paramaters for specific shipping routes which may be feasible to the year 2000. Some of the routes are presently used on a regular seasonal basis, while others have seldom or never been transited by surface shipping. The routes were divided into discrete segments so that values can be defined for a particular shipping project rather than for the Arctic as a whole, since the latter would impose unreasonable limits on the design criteria.

The information comes from a large number of publications which are referenced in the text and listed in the bibliography in volume II.

3.2 Ice

3.2.1 General

Sea ice and glacial ice occur throughout the Arctic and will have a major effect on the viability of shipping systems in that area. This section presents a general discussion of sea and glacial ice, before presenting a detailed discussion on the incidence, dynamics and importance of these ice types in the specific Arctic area which are being considered in this review.

3.2.2 Glacial Ice

Some Arctic marine areas are subject to incursion from pieces of floating glacier ice. These are classified by size as ice islands, icebergs, bergy bits, and growlers (Maxwell, 1980).

An 'ice island' is a piece of glacier ice which has broken away from an ice shelf. It has a freeboard of about 5 metres, thickness of 30 to 50 metres and can be from several to more than 100 kilometres across (CHS, 1982). Most ice islands in the Canadian Arctic are derived from the Ward Hunt Ice Shelf on the north coast of Ellesmere Island. They follow the east to west drift in the Arctic Ocean and Beaufort Sea. Fragments from ice islands have been tracked drifting through the Parry Islands and then along the Beaufort coast (Markham, 1981; Arctec, 1983).

An 'iceberg' is a piece of ice which has broken from the end of a tidewater glacier and which has a freeboard of 5 metres or more (A.E.S. 1980). While an ice island is similar in size to an island, an iceberg is similar in size to a ship. The size of an iceberg is dependent on the thickness and extent of floating glacier ice from which it was derived and on the duration of melting since it was calved. The freeboard is dependent on the iceberg shape and density. Glacier ice has a density of about .9 compared to water and, therefore, only one tenth the mass of an iceberg protrudes above water. Iceberg shapes range from pinnacled to spherical and change constantly as the iceberg melts. Typical height to depth ratios range from 1:1 for pinnacled bergs to 1:5 for blocky bergs (CHS, 1982).

As an iceberg drifts it melts and also fragments mechanically. Iceberg fragments are termed bergy bits when their freeboard is greater than 1 but less than 20 metres and growlers if they are less than 1 metre.

Icebergs are found in regions crossed by currents which have passed in front of tidewater glaciers. They are most prevalent in Baffin Bay and Davis Strait, where they are carried after calving from glaciers on the coast of Greenland, Ellesmere and Devon Islands. They are also carried by currents into Lancaster Sound and Hudson Strait but, with the exception of ice islands, do not occur in the western Arctic.

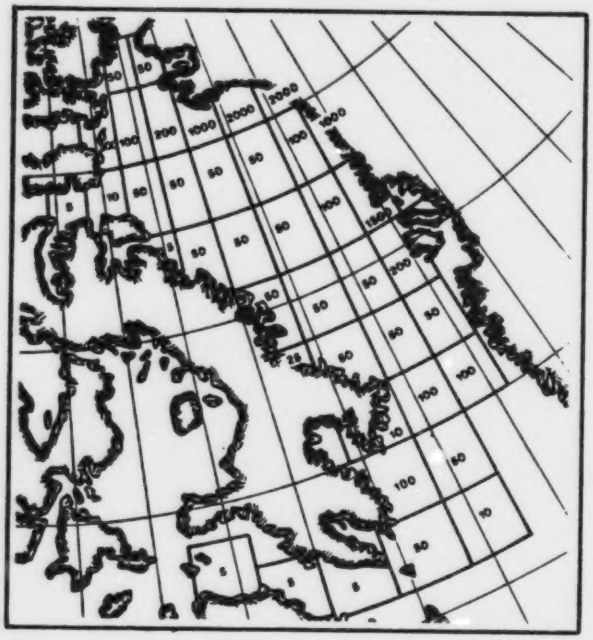
Typically, icebergs are calved from glaciers on the coast of Greenland between Disko Island and Cape Alexander. They drift north with the Greenland Current and make a circuit of Baffin Bay, then drifting south along the Canadian coast. Thousands are calved each year and 40,000 or more may be present at any one time (Markham, 1981). Concentrations are highest near the coastlines and are highest in northern areas in the spring, when they are released from the pack ice. Concentrations are highest in the south later in the summer after they have drifted from the north.

Statistics on the frequency of occurrence of icebergs are not very reliable because of the difficulty of accurate counts over such a large area. Relative frequency, based on observation by the International Ice Patrol (1948-1978), are shown in Figure 3.2.1 (Arctec, 1983). The numbers reflect the seasonal cycle of drifting icebergs in the eastern Arctic.

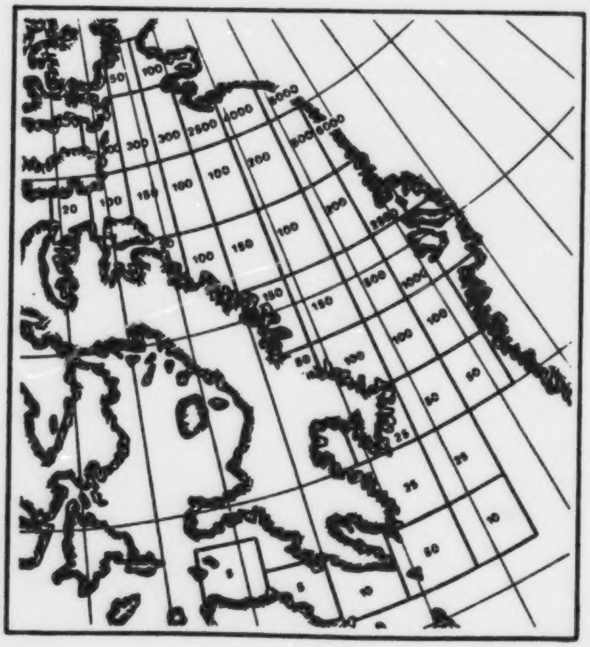
Statistics on the dimensions of icebergs are also not very reliable nor very common because of the difficulties of measurement. Icebergs in the Arctic are certainly larger than those in the Labrador Sea but no reliable measurements are available to show this.

FIGURE 3.2.1

ICEBERG POPULATION
BAFFIN BAY AND DAVIS STRAIT



MARCH 1 - 31



SEPT. 1 - 30

ESTIMATED POPULATION
IN 2°x 4° ZONE OF
ICEBERGS > 100 m DIA

3.2.3 Sea Ice

Most of the Canadian ocean area is covered seasonally by sea ice. At a small scale the ice cover appears as a homogeneous mass which expands and contracts seasonally. Closer study shows that it exhibits annual patterns of growth and decay and that it includes several different types of ice, each with its own features and physical properties.

Several types of sea ice occur in Arctic Canada, distinguished on the basis of age. The main subdivisions are first year ice and old ice.

First year ice is ice from a few millimetres to about 2 metres in thickness, which forms and melts completely within one annual cycle (generally October through September). When an ice floe or sheet does not melt entirely from one year to the next it is termed second year ice and in subsequent years, multi-year ice. Second and multi-year ice are in practice difficult to distinguish and are therefore alternately described as old ice (Markham, 1981).

Patterns of occurrence of first year and old ice vary from year to year but can be characterized over the long term. Figures 3.2.2 shows the median concentration of all ice, based on about 20 years of record, for September and March (Markham, 1981). These are the months of minimum and maximum ice cover at most locations in the Arctic. Figures 3.2.3 show the median concentration of old ice (Arctec, 1985).

3.2.3.1 Growth

Expansion of the ice cover during fall and winter is due to two phenomena: ice growth and ice drift. Ice growth begins when the water surface temperature falls below its freezing temperature (typically -1.8°C for sea water). Ice begins to form as platelets, called frazil, which then coalesce to form a thin ice sheet. Vertical growth occurs as heat is lost from the ice surface and as sea water freezes at the bottom of the ice sheet.

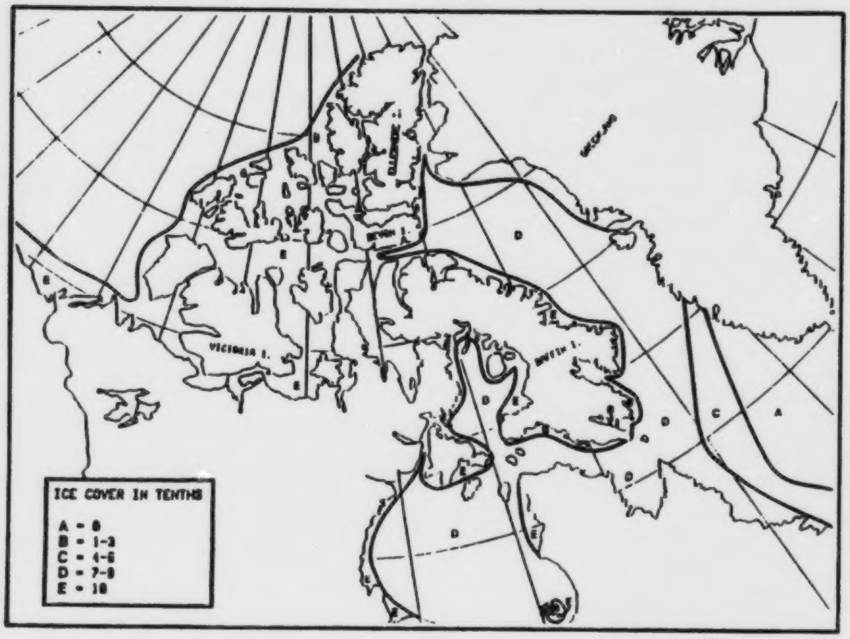
The rate of ice growth is controlled by the water and air temperatures and wind speed and also by the ice thickness. As the ice thickens the rate of energy loss from its surface slows down and the rate of growth also slows such that first year ice thickness in Arctic Canada is limited to about 2 metres.

When the air temperature rises above freezing in spring, the rate of energy loss from the ice surface falls below the rate of heat gain from the underlying water and the ice cover begins to melt. Ice melt is assisted by the expansion of microscopic brine channels within the ice sheet and also by mechanical agitation and break-up of ice floes.

The approximate spatial pattern of first year ice thickness in the Arctic during late winter is illustrated in Figure 3.2.4 (Markham, 1981). The general pattern is one of gradually increasing thickness toward the central Arctic, with the thinnest ice occurring in Davis Strait. The

FIGURE 3.2.2

MEDIAN SEA ICE CONCENTRATION


ICE COVER IN TENTHS
A - 0
B - 1-3
C - 4-6
D - 7-9
E - 10
VICTORIA I.
BAFFIN I.
DEVON I.
ELLESMERE I.
GREENLAND
A
B
C
D
E

LATE
MARCH

LATE
SEPTEMBER

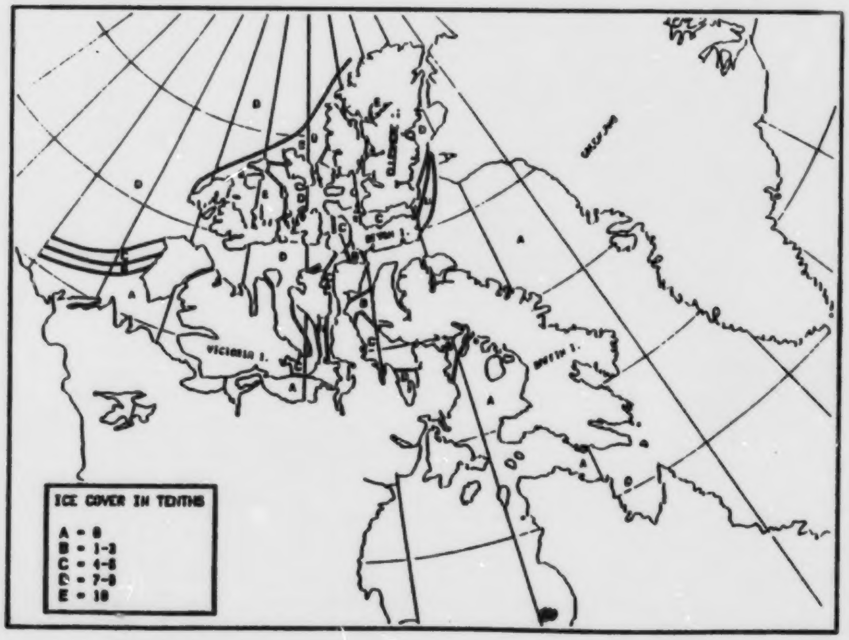
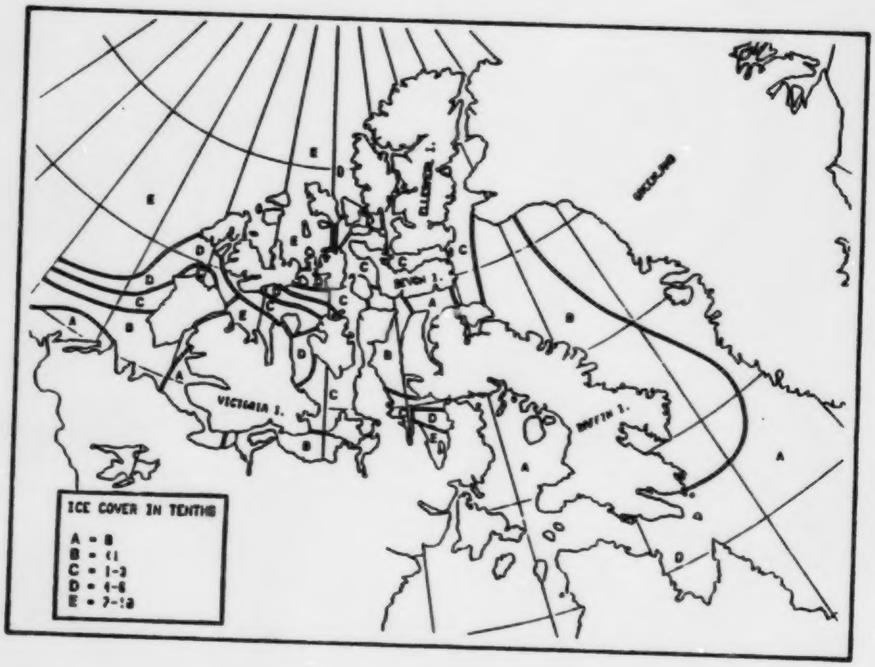
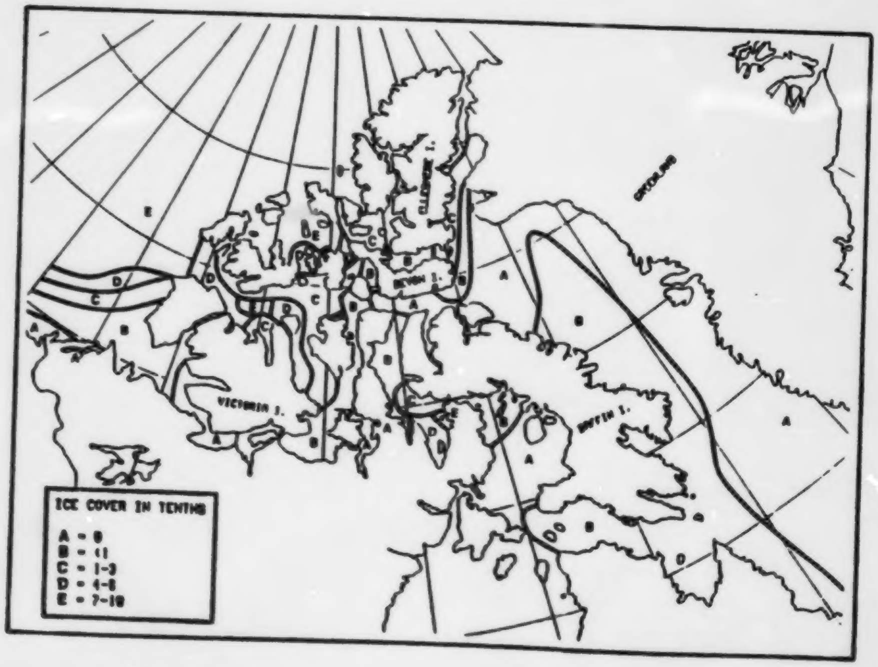

ICE COVER IN TENTHS
A - 0
B - 1-3
C - 4-6
D - 7-9
E - 10
VICTORIA I.
BAFFIN I.
DEVON I.
ELLESMERE I.
GREENLAND
A
B
C
D
E

FIGURE 3.2.3

CONCENTRATION OF OLD ICE


ELLESMERE I.
GREENLAND
DEVON I.
VICTORIA I.
BAFFIN I.
ICE COVER IN TENTHS
A = 0
B = <1
C = 1-3
D = 4-6
E = 7-10

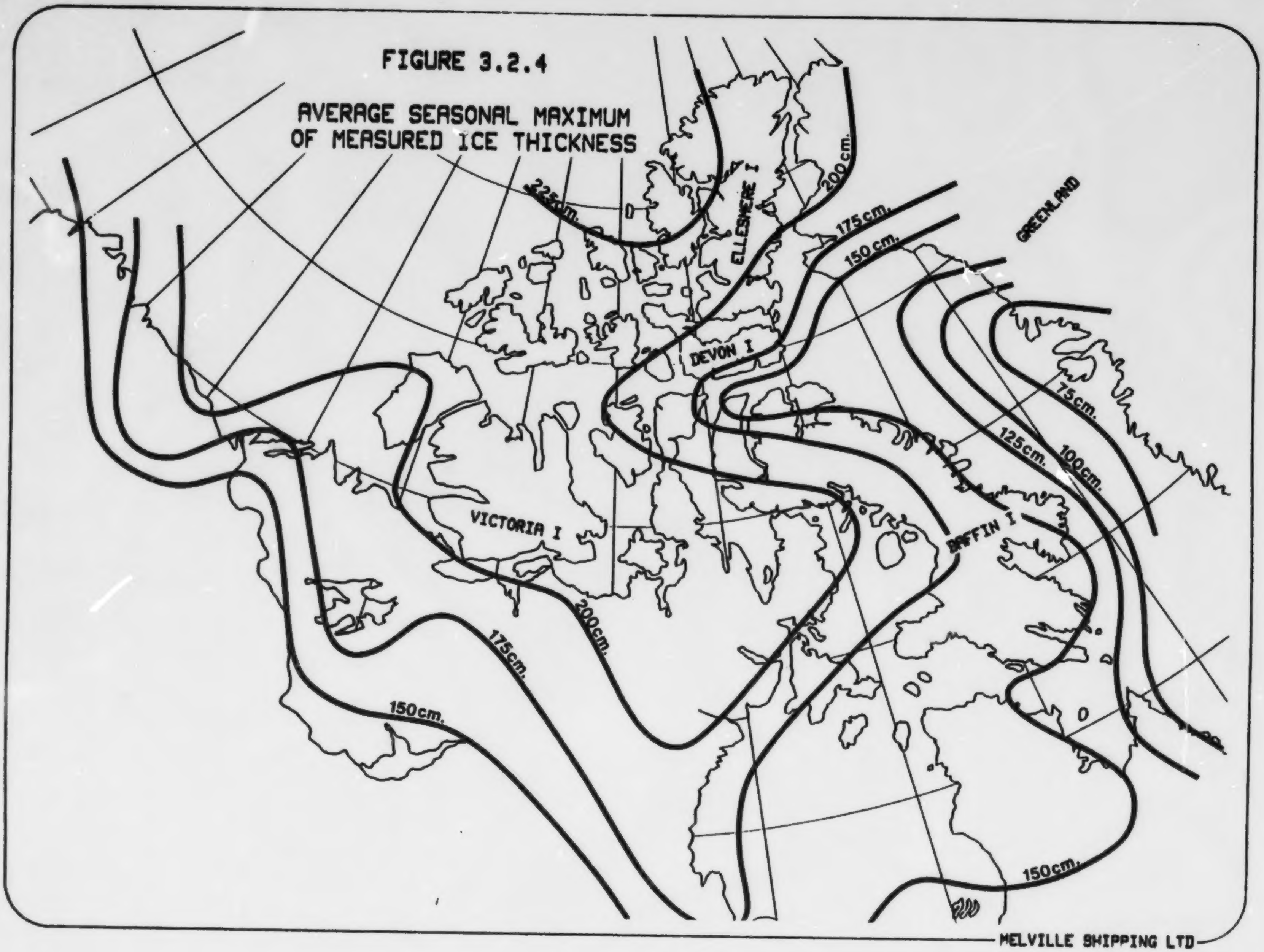
MARCH


ELLESMERE I.
GREENLAND
DEVON I.
VICTORIA I.
BAFFIN I.
ICE COVER IN TENTHS
A = 0
B = <1
C = 1-3
D = 4-6
E = 7-10

SEPTEMBER

FIGURE 3.2.4

AVERAGE SEASONAL MAXIMUM
OF MEASURED ICE THICKNESS


GREENLAND
ELLESMERE I
DEVON I
BAFFIN I
VICTORIA I
225cm.
200cm.
175cm.
150cm.
125cm.
100cm.
75cm.
200cm.
175cm.
150cm.
150cm.

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pattern of ice thickness closely reflects the influence of air and sea temperatures, as detailed elsewhere in this report.

3.2.3.2 Drift

The seasonal patterns and variability of ice cover extent are due only in part to growth and melting. Variations in ice concentration and extent are also caused by drift of ice floes from one place to another. Ice drift also affects average ice thickness, since floes from northern source areas can be carried south into areas of thinner local ice.

Ice in the Beaufort Sea is carried in a clockwise rotation by a current called the Beaufort Gyre. This carries ice floes from the western side of the Arctic Archipelago along the North American Arctic coast to the Chukchi Sea. On a shorter time scale, floes move on and off shore along the Beaufort coast in response to winds and local current eddies during summer, and in response to a southward expansion of the Polar Pack in winter.

In the Arctic Archipelago, sea currents are relatively weak but tend to move the ice toward the southeast during summer, as it breaks up to the north of Parry Channel. Winds have an important effect on ice drift here, contributing to the net south eastward drift out of Lancaster Sound.

3.2.3.3 Strength

Like thickness, the mechanical properties of sea ice vary in time and space. The factors which govern ice strength include temperature, salinity, air void volume, brine volume, crystal size and orientation. The primary factor is brine content which is a function of the age and temperature history of the ice, as well as the salinity of the water from which it is formed. As sea ice becomes older or colder it becomes stronger and more brittle.

The variability in the strength-governing factors make exact definition of ice strength at a particular location highly dependent on conditions during a particular measurement. Derived estimates based on average values of temperature and salinity indicate typical values for flexural strength of first year ice of less than 1 MPa and for old ice of about 1.0 MPa. Estimates of compressive strength are in the range of 2 to 4 MPa for first year ice and 4 to 8 MPa for old ice.

3.2.3.4 Ridging

Differential pressure in an ice sheet results in ridging, as the ice sheet either buckles or shears to reduce stress. The relative frequency of ridging depends on the frequency and magnitude of pressure events in the ice pack or sheet, and on the strength of the ice.

No comprehensive geographical database of pressure ridge occurrence is presently available for the Canadian Arctic, and an accurate quantitative estimate for the entire region cannot be given. The principal locations of known heavy ridging include:

- the northeast coast of Bylet Island,
- Victoria Strait,
- Ungava Bay,
- the shear zone of eastern Beaufort Sea and surrounding St. Lawrence Island.

Like ridge frequency, relatively few measurements have been analyzed to describe long-term average values of ridge thickness and geometry. In general, ridge thickness and block size within a ridge are related to thickness of the surrounding ice. Most ridges in the Northwest Passage are less than 2 meters in height while, in areas such as the southern Beaufort Sea, sails can exceed 10 metres.

Ridge building processes result in three typical geometries. Thin ice tends to raft rather than buckle and results in regular, smooth surfaces twice or more times the level ice thickness. Thicker ice is buckled by pressure and results in piles of broken blocks. Finally, ridges resulting from shearing motion tend to have steeper faces and higher sails than pressure ridges. In all cases, newly formed ridges are long piles of blocks which have air voids above water level and water or slush voids below. With time, the blocks become cemented together and voids are filled with refrozen melt water. Thus, regions of mobile ice will tend to have ridges which are weakly consolidated while regions of stable ice cover will have more consolidated ridges. With time, the sail height is reduced as the above water surface is melted and eroded.

3.2.4 Shipping Oriented Geographic Review

While the statistics of the occurrence of various environmental features are of interest, it is mainly the dynamics and make-up of the ice cover in specific areas which is of most importance. This section provides a shipping oriented geographical review of the Arctic environment. The glacial and sea ice hazards are discussed for each area based on the experience of mariners and shipping companies and particularly based on the most recent experience gained in the eastern Arctic by the M.V. ARCTIC. A map which identifies each geographic area to be discussed is provided in Figure 3.2.5.

3.2.4.1 Baffin Bay and Davis Strait

a) Glacial Ice

The large number of glaciers feeding into Baffin Bay produce floating glacial ice hazards in extremely high quantities. The area of highest iceberg concentrations spans from Disko Island to the entrance of Melville Bay. More than 50 icebergs per hour have been recorded passing within 12 nautical miles of a vessel in this region (Robson, 1982). Iceberg concentrations are the highest near the Greenland Coast. Figure 3.2.6 illustrates a typical navigation through this region. The highest occurrence of encounters by a ship with glacial ice will occur in mid-June when vessels travel close to the Greenland coast following the west Greenland lead. Lower concentrations tend to be encountered during July and early August when vessels will travel closer to the centre of Baffin Bay.

The second area of high iceberg concentrations occurs close to the Baffin Island coastline between Cape Christian and Cape Dyer. These incidents usually occur in the late summer and early fall period when vessels follow the west side of Baffin Bay to take advantage of the south flowing Baffin Current on south bound voyages.

b) Sea Ice

The Baffin Bay sea ice regime is predominantely first year ice containing a small percentage of old ice which originates from Smith Sound. Currents and winds are the main factors which influence this ice regime. A weak warm current, the west Greenland current, flows north along the west Greenland coast while a stronger cold current, the Baffin current, flows down the Baffin Island coastline. These two currents mix in a complex cross bay flow in Baffin Bay.

First year ice, in various stages of thickness, occurs in Baffin Bay by early May. The major features of the Baffin Bay ice regime during the early spring break-up are:

- The north water
- Open water at the entrance to Lancaster Sound
- Western Baffin Bay ice boundary
- Eastern Baffin Bay ice boundary
- Central Baffin Bay ice cover

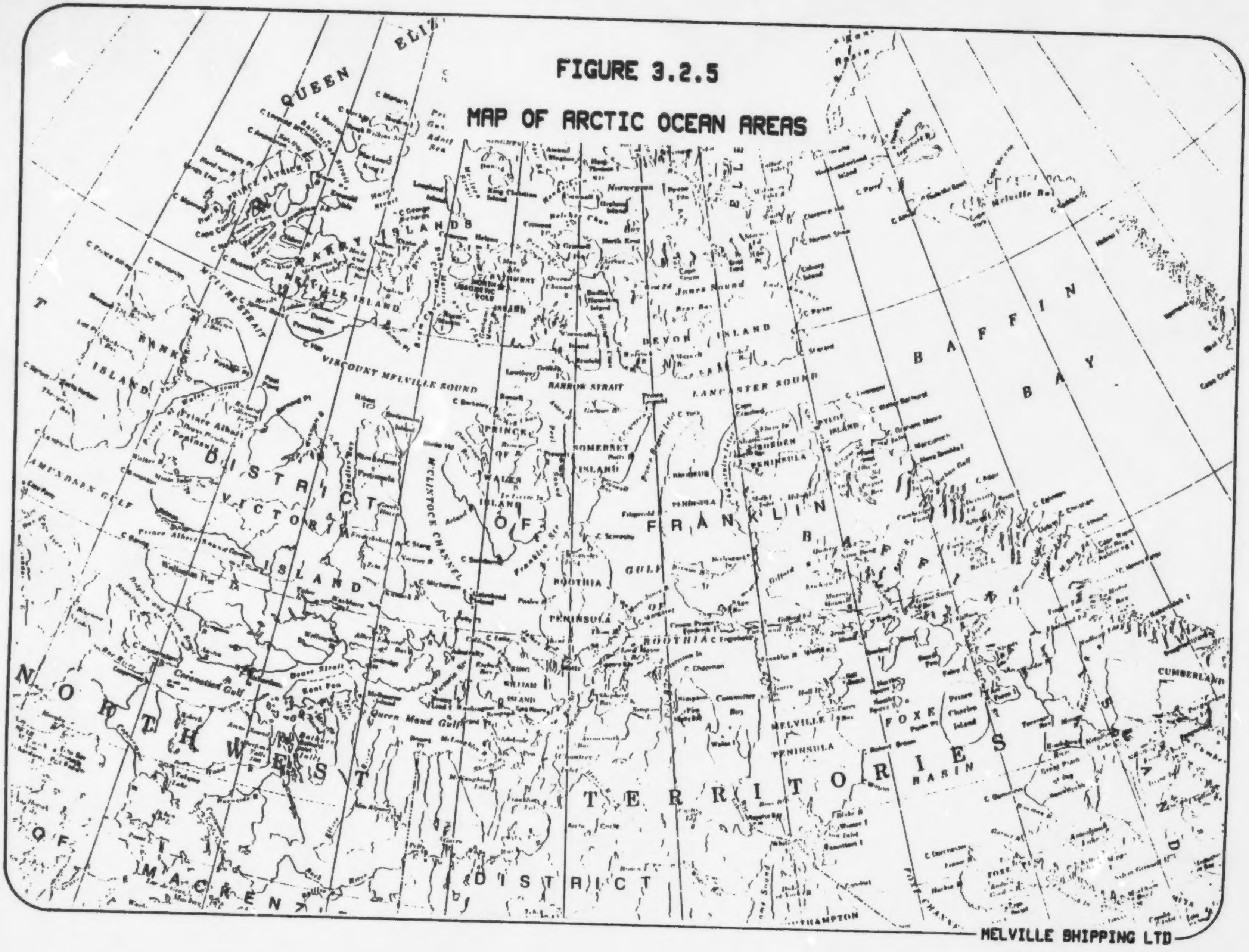
Between mid-May to mid-July the major change in the Baffin Bay ice regime occurs from the joining of the north water with the open water of Lancaster Sound to form the north western Baffin Bay pack ice edge. The eastern Baffin Bay ice edge remains essentially stationary throughout June and only in good ice years does it move west of 60°W in July.

By early June the high ice concentration becomes a matrix of closely packed floes rather than an ice cover punctuated by leads which are prevalent during the winter period. Ice conditions at the start of June do not appear to be necessarily indicative of the ice break-up and movement in subsequent weeks (Polar Research and Engineering, 1983a).

The west Greenland lead opens along the Greenland coast to north of Disko Island by late May. This early break-up is the result of thinner ice conditions caused by the warmer water of the west Greenland current. This, combined with the eastward expansion of the north water into western Melville Bay, facilitates the early season entry for a vessel such as the M.V. Arctic through Baffin Bay.

FIGURE 3.2.5

MAP OF ARCTIC OCEAN AREAS


QUEEN ELIZ
ELLE
PARRY ISLANDS
MELVILLE ISLAND
M'CLURE STRAIT
BANKS ISLAND
VISCOUNT MELVILLE SOUND
BARROW STRAIT
LANCASTER SOUND
DEVON ISLAND
Jones Sound
BAFFIN BAY
Melville Bay
Prince Patrick I
AMUNDSEN GULF
DISTRICT OF FRANKLIN
VICTORIA ISLAND
PRINCE OF WALES ISLAND
M'CLINTOCK CHANNEL
SOMERSET ISLAND
BOOTHIA PENINSULA
GULF OF BOOTHIA
BAFFIN
FOXE BASIN
Prince Charles Island
MELVILLE PENINSULA
Queen Maud Gulf
Coronation Gulf
NORTHWEST TERRITORIES
DISTRICT OF MACKENZIE
CUMBERLAND
FOXE CHANNEL
SOUTHAMPTON

MELVILLE SHIPPING LTD

The ice cover of Baffin Bay reduces through July and August so that by mid-August the pack ice is located between the latitudes of 74°N and 65°N. There is a high degree of variability in this reduction, with a clear open water route through Baffin Bay developing as early as mid-June or as late as mid-September. Vessels transiting Baffin Bay may occasionally encounter strips of decaying first year ice and old ice in the centre of the bay as the ice reduces.

New ice begins to form during the last half of September in the north western sections of Baffin Bay. On average, this growing ice spreads southward across the approaches to Jones Sound during the last week of September, across the approaches to Lancaster Sound during the second week of October and to Frobisher Bay by the second week of November.

The first permanent ice in Baffin Bay usually develops during the second week of October. A rapid seaward expansion of the ice cover occurs during the later half of October and spreads to all but the west coast of Greenland by the end of November. The lead along the Greenland coast gradually retreats southward to near latitude 72°N in December and to as far south as latitude 68°N by mid-January.

The occurrence of old ice in Baffin Bay produces a significant hazard to shipping in the region. There are two source areas for old ice in Baffin Bay and Davis Strait. These are:

- The significant amount of old ice from the Arctic Basin moving south through Nares Strait into northern Baffin Bay during the summer and early winter period; and

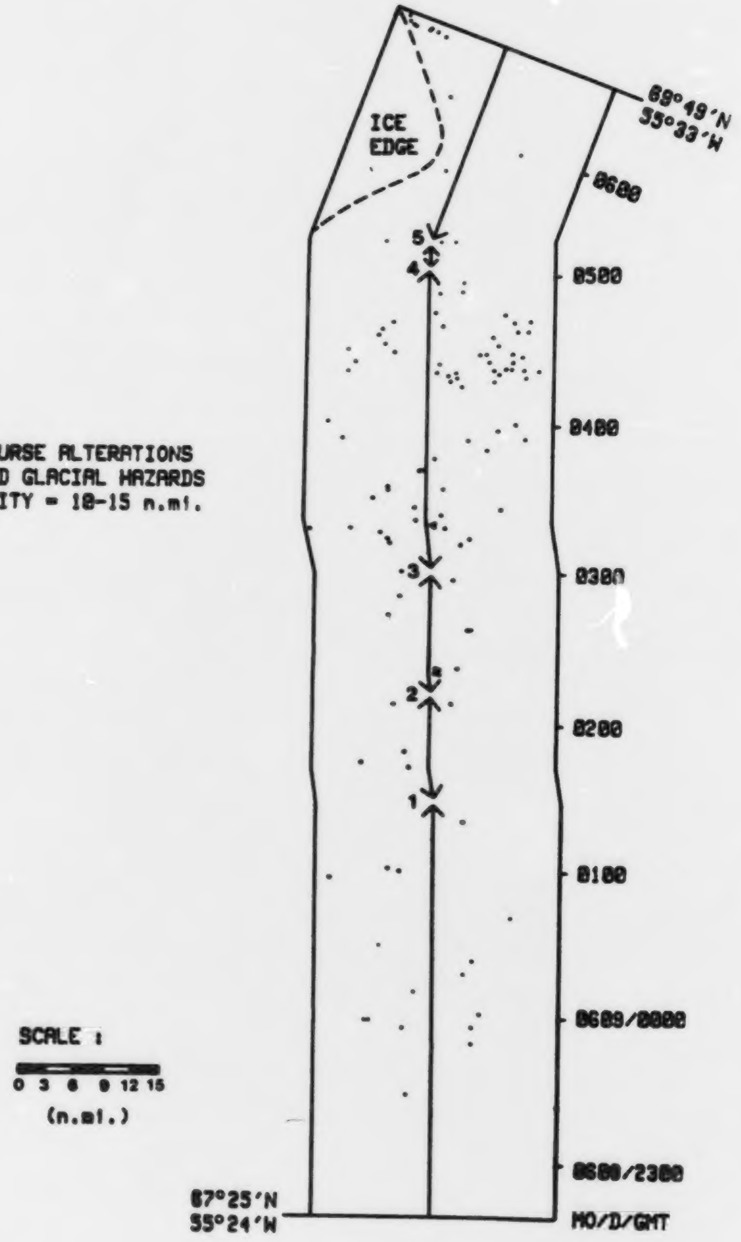
- A small amount of old ice which may move into Davis Strait from east Greenland around Cape Farewell, often called Storis, in the late spring and early summer.

The movement of old ice into northern Baffin Bay is initiated in July by the fracturing of an ice bridge which forms each year across Smith Sound at the northern extremity of the Bay. The old ice in the Kane Basin is then free to drift south along the east coast of Ellesmere Island, past Coburg Island to Devon Island by mid-September. During years of heavy and early old ice flux out of this area, old ice will drift south past Devon Island and across the entrance to Lancaster Sound by early September. In years of delayed or light old ice movement, this may not occur until late November, if at all.

When this old ice reaches Lancaster Sound, the complex currents will move some of the ice into the Sound. The old ice will then drift south with the cold Baffin Current along the west side of Baffin Bay into Davis Strait and subsequently across Hudson Strait. Old ice floes tend to break down as they move south through Smith Sound resulting in small floe sizes drifting south into Baffin Bay. Old ice thicknesses will exceed four metres, however, during the summer it has been reported that the ice strength drops significantly (Norland, 1984a). This implies that old ice may pose less of a hazard during the summer and early fall than during winter and early spring.

FIGURE 3.2.6

TYPICAL NAVIGATION THROUGH LARGE ICEBERG POPULATION NEAR DISCO ISLAND, GREENLAND


ICE EDGE
69°49'N
55°33'W
0600
0500
0400
0300
0200
0100
0609/0000
0608/2300
MO/D/GMT
67°25'N
55°24'W
1
2
3
4
5
SCALE :
0 3 6 9 12 15
(n.mi.)

NOTE : FIVE COURSE ALTERATIONS
TO AVOID GLACIAL HAZARDS
VISIBILITY = 10-15 n.mi.

MELVILLE SHIPPING LTD

Generally, the Smith Sound ice bridge will form between early November to late January. This prevents movement of old ice and, consequently, no old ice occurs in northern Baffin Bay in the spring and early summer with the exception of old ice frozen into land fast ice. However, high concentrations of old ice may occur in central and southern Baffin Bay near the Baffin Island coastline and may be encountered by a vessel in the summer period. The highest concentrations of old ice occur between Cape Christian and Cape Dyer for central Baffin Bay.

The old ice moving into Davis Strait from east Greenland is heavily weathered and in small floe sizes. This tends to occur in the June and July period in years when significant old ice is moving down the east Greenland coast from the Greenland Sea. A vessel navigating away from the Greenland coastline would avoid this ice.

3.2.4.2 Lancaster Sound and Admiralty Inlet

a) Glacial Ice

There are two source areas for glacial ice hazards in Lancaster Sound;

- Glacial ice carried by the inflowing current from Baffin Bay, and
- Glacial fragments from the Devon and Bylot Island icecaps.

Icebergs caught in the inflowing current from Baffin Bay drift into Lancaster Sound as far west as Cape Warrender, Devon Island. These icebergs then travel south across Lancaster Sound to Bylot Island where they enter the east flowing current and exit Lancaster Sound. Occasionally, factors which are not presently well understood will drive these icebergs further west into Lancaster Sound. Such factors may include current fluctuations where the inward flowing current surges further west or strong easterly winds. On such occasions, icebergs may travel south into Admiralty Inlet. Only very rarely will icebergs be encountered west of Admiralty Inlet in Lancaster Sound and these are usually small, calved from the small glaciers feeding into the inlets of Devon Island as far west as Blainley Bay. The furthest westerly sighting of a glacial ice hazard from the M.V. Arctic was an iceberg off the south east tip of Cornwallis Island, grounded in shallow water off Cape Hurd.

Generally, the highest concentrations of icebergs occur east of Cape Warrender to the entrance of Lancaster Sound with numbers exceeding 400 to 500 (Intera, 1985). The distribution of icebergs in Lancaster Sound is seasonal. The formation of the Smith Sound icebridge between mid-November and late January stops the flow of icebergs out of Nares Strait and from mid-December there is a gradual reduction in the number of icebergs in Lancaster Sound so that by the late winter and spring period the Sound is virtually iceberg free except for those frozen into the fast ice. The fracturing of the Smith Sound ice bridge in July and the releasing of icebergs from shore fast ice gradually increases the number of icebergs in the Sound during the summer and early fall period.

b) Sea Ice Conditions

The Lancaster Sound sea ice regime is a complex arrangement of first year and multi-year ice which is highly variable depending on the time of year. Currents and winds are the main factors which affect the ice regime of Lancaster Sound. A dominant west to east flowing current in the Sound results in a net ice flow in this direction; however an inflowing current from Baffin Bay may bring large quantities of old ice into the Sound in the October - November time period from northern Baffin Bay. The ice pattern of Lancaster Sound is complex and poorly understood.

The degree of consolidation which occurs in Lancaster Sound over the winter months can be highly variable. In some years Lancaster Sound does not consolidate and remains mobile throughout the winter. In these years, clearing of the Sound occurs early in May leaving an ice front as far west as western Barrow Strait. In other years Lancaster Sound may consolidate to as far east as Navy Board Inlet resulting in a late May ice front at this location. There are five locations where the consolidated ice edge may form in Lancaster Sound during the winter period. These are shown in Table 3.2.1 together with the years in which the ice edge was located at each position. The factors which contribute to the variability of consolidation in Lancaster Sound are not well understood. It has been speculated that the degree of consolidation during the winter months is directly related to the strength of the winds (Markham, 1981). It is likely that calm winds combined with severe winter temperatures result in increased consolidation in the Sound.

Consolidation will not usually occur in Lancaster Sound until the mid to late winter. Consequently, an active shear zone develops between the consolidated ice of Admiralty and Navy Board Inlets and the mobile ice of Lancaster Sound. A ridge may develop to a height of several metres depending on the severity of the year. The shear zone across Navy Board Inlet has been observed developing in early November over a one week period due to heavy ice pressures associated with the cross channel flow of old ice.

Clearing of ice from Lancaster Sound east of the ice edge occurs rapidly from mid-May. The gradual rise in temperatures quickly expand the open water areas in eastern Lancaster Sound. This, combined with the easterly ice flow and prevailing north west winds, contributes to rapid clearing. By early June the open water of Lancaster Sound will combine with the North Water in Baffin Bay.

By late June the consolidated ice of Lancaster Sound and Admiralty Inlet becomes extensively puddled. Ice thicknesses average 1.75 to 1.85 meters over much of the Inlet with some areas exceeding 2.0 meters. Ice thicknesses tend to be lower in consolidated ice years, averaging just over one metre. Generally, it has been found that the ice thickness in Admiralty Inlet will vary by no more than ten percent from year to year and that ice thickness is independent of consolidation in Lancaster Sound.

These findings indicate that winter temperatures alone are not necessarily the determining factor in the degree of consolidation of Lancaster Sound.

During years when the ice in Lancaster Sound consolidates, it usually begins to fracture in the second or third week of July. Admiralty Inlet will tend to fracture one to two weeks later. In these years, thick first year ice will be encountered in Lancaster Sound in gradually reducing concentrations until early September. In years when the Sound does not consolidate over the winter, it is virtually ice free by the end of June.

Small quantities of old ice from Barrow Strait and Wellington Channel may enter Lancaster Sound during the summer open water period. However, the flow sizes tend to be small and scattered. Slightly higher concentrations of old ice may enter Lancaster Sound from Barrow Strait in the fall and early winter period when the old ice is not subject to decay following the east flowing current.

New ice formation usually begins during the last two weeks of September in Barrow Strait and extends eastward during October to the entrance to Lancaster Sound. By the last week of October and the first week of November grey-white to thin first year ice will be encountered throughout Lancaster Sound. Consolidation occurs in Navy Board Inlet in late October and in Admiralty Inlet in late December.

The most significant event during the fall is the high concentration of multi-year ice which may move into the Sound from Baffin Bay. The fracturing of the Smith Sound ice bridge in July releases a high concentration of old ice into northern Baffin Bay. This ice slowly drifts to the entrance of Lancaster Sound in concentrations up to six to eight tenths by late September. Some of this ice will enter the inflowing current along the southern coast of Devon Island. This is highly variable, with old ice recorded moving into Lancaster Sound from Baffin Bay as early as late August in severe years to late November in light years. The factors which influence this variability are poorly understood. Easterly winds may assist driving the ice far into Lancaster Sound and observations of high concentrations of old ice and icebergs far to the west of the expected end of the west flowing current at Cape Warrender support this supposition. The floe sizes of this old ice range from vast (2-10km) to a very high proportion of small (20-100m) floes (Intera, 1985).

The old ice that enters the north side of Lancaster Sound will follow the currents and flow across to the south side near Navy Board Inlet. This ice will exit the Sound along the north shore of Bylot Island. The formation of the Smith Sound ice bridge from late November to late January prevents further movement of old ice into northern Baffin Bay and Lancaster Sound and, consequently, there is a gradual reduction of old ice so that by the early spring period no old ice is usually expected at the entrance of Lancaster Sound except for floes that are frozen into land fast locations.

Factors which influence the old ice at the entrance to Lancaster Sound during the fall are:

TABLE 3.2.1

WINTER CONSOLIDATED ICE EDGE LOCATION

Lancaster Sound
1964-1985

LOCATION	YEARS	
Resolute	1964 1969 1974 1976	
Prince Leopold Island	1965 1966 1967 1968 1971 1982	1973 1975 1977 1980 1981 1985
Brodeur Peninsula	1982	
Cape Yorke	1970 1984	
Navy Board Inlet	1978 1979 1983	

- Cold temperatures - due to the cold temperatures the old ice floes are very strong.

- Pressure - due to the rapid formation of first year ice types around the old ice floes, significant pressures can be created.

- Extent - the old ice can occur over a wide area.

- Floe Sizes - large and vast floes have been observed to produce pressure around their immediate area. This is likely due to their different inertia to movement from currents and winds from the surrounding first year ice. The occurrence of high concentrations of very small old ice floes poses problems of detection and avoidance.

3.2.4.3 Barrow Strait and McDougall Sound

a) Glacial Ice

Glacial ice fragments in Barrow Strait and McDougall Sound are very rare. Fragments of glacial ice from northern Ellesmere Island may enter the Sverdrup Basin and, subsequently, Barrow Strait from Byam Martin Channel and Penny Strait. For example, several large ice island fragments occurred in Barrow Strait in 1977 having travelled down Byam Martin Channel in 1974 and 1975.

b) Sea Ice Conditions

The sea ice regimes of Barrow Strait and McDougall Sound are a complex arrangement of old and first year ice. Winds are an important factor in the distribution of ice in this region. There is a west to east flowing current in Barrow Strait and a north to south current in McDougall Sound. Current have much less of an effect on the ice regime in this region than they do further east in Lancaster Sound and Baffin Bay.

Central and western Barrow Strait and McDougall Sound always consolidate during the winter period. During the winter the northern section of the region is dominated by thick first year ice with traces of old ice. The southern section contains a higher proportion of old ice varying between one to four tenths.

There is a consistant pattern of break-up in Barrow Strait. The edge of consolidated ice fractures back to Resolute and Somerset Island by mid-July in most years. Extensive ponding occurs on the consolidated ice cover of western Barrow Strait and McDougall Sound throughout July.

Preliminary field investigations during early July indicate that the properties of the ice of McDougall Sound are remarkably similar to Admiralty Inlet (FMS, 1983; Norland, 1984b). Small open water areas may develop around shore locations during July. In average years the ice bridge will remain at Resolute until the third week of July before fracturing. However, this event is highly variable between late June to mid-August.

The factors which influence the timing of fracture are not well understood but may include the number of melting degree days experienced during the spring and the presence of favourable strong west or north west winds. Since the currents are weak in this region, winds play an important role in initiating fracture.

The fracturing of western Barrow Strait and Viscount Melville Sound occurs very rapidly, usually over a one to three day period. Once this fracturing is complete, the easterly flow of ice out of Barrow Strait is very slow. For most of the month of August nine tenths ice conditions persist throughout central and western Barrow Strait. The numerous small islands in central Barrow Strait such as Lowther, Young and Hamilton Islands, serve to anchor the ice in Barrow Strait retarding eastward movement.

The prevailing wind in this area is from the north west and, consequently, a narrow open water lead will form across northern Barrow Strait into Viscount Melville Sound under favourable conditions by mid-August. The predominant cause of ice reduction in Barrow Strait is in situ melt during the summer season. There is a gradual reduction from the northern section of Barrow Strait to the south as the lead slowly widens. A small amount of ice, mostly old ice, drifts eastward across the north shore of Somerset Island and past Prince Leopold Island into Prince Regent Inlet by late August. By mid-September Barrow Strait is mostly open water with a small percentage of old ice occurring along the Somerset Island coastline with up to one tenth concentration occurring throughout the remainder of the channel.

There is a consistent pattern of freeze-up in Barrow Strait. New ice forms in the last two weeks of September and gradually increases in thickness to grey-white and thin ice by mid-October. McDougall Sound consolidates by late October but Barrow Strait remains mobile much later. Consequently, extensive rubbling and ridging develops between the mobile ice of Barrow Strait across the consolidated ice edge of McDougall Sound and Resolute passage. This may develop into a significant shear zone and rubble field by the time western Barrow Strait completely consolidates later in the winter.

The islands of central Barrow Strait form an anchor for the developing new ice. Consolidation usually begins with an ice bridge forming between Russell Island, Young Island, and Lowther Island. This is followed by a ice bridge between Resolute, Griffith Island and Somerset Island. Further ice bridges at Prince Leopold Island and points further to the east may develop in some years. The variability in timing of the formation of these bridges can be broad with complete consolidation occurring as early as late October or as late as mid-March. Due to the dynamic nature of the ice regime during freeze-up, Barrow Strait is characterized by heavily ridged ice during the winter period.

A variable amount of old ice may move into Barrow Strait. Generally, a high percentage of old ice may be expected if the previous year had severe ice conditions. In these years, less in situ reduction of the ice cover occurred in western Barrow Strait and Viscount Melville Sound, leaving more old ice for the following season.

There are four sources of old ice in Barrow Strait;

- Viscount Melville Sound
- Byam Martin Chanel
- McDougall Sound and Wellington Channel, and
- First year ice which survives the summer melt in Barrow Strait or McDougall Sound.

Currents are more of a factor in ice movement in McDougall Sound and Wellington Channel in Barrow Strait. Multi-year ice in McDougall Sound and Wellington Channel generally occurs in the open water period and is controlled by a number of factors such as, the movement of old ice out of Penny Strait along the west side of Queen's Channel, and the existence of an ice bridge which may form across Crozier Strait. Ice drift rates were found to vary between 2 to 40 km/day in this area (Polar Research and Engineering, 1982). The occurrence and fluxuation of currents in this region are poorly understood.

A small amount of old ice drifts south along the eastern shore of Cornwallis Island in Wellington Channel during the fall. This will produce low concentrations of old ice in small floe sizes in eastern Barrow Strait at the entrance to Wellington Channel. These floes become incorporated into the frozen ice matrix over the winter.

3.2.4.4 Viscount Melville Sound and Byam Martin Channel

a) Glacial Ice

Glacial ice fragments are rare. Large ice island fragments have been recorded moving south through Byam Martin Channel from the Prince Gustaf Adolf Sea and the Arctic Basin. The last occurrence of an ice island fragment was in 1974 to 1977.

b) Sea Ice Condition

The winter sea ice regime of the Viscount Melville Sound and Byam Martin Channel region is a complex arrangement of thick first year and old ice. A high percentage of old ice, exceeding four to eight tenths, occurs across southern Viscount Melville Sound in a wide range of floe sizes. Thick first year ice occurs across the northern section of the Sound with extensive rubbling and ridging during the winter period.

The occurrence of old ice in southern Byam Martin, Austin and Byam Channel during the winter period can be highly variable. In years when the Byam Martin Channel ice bridge does not fracture this area is all first year ice. In years of ice bridge fracture, high concentrations of old ice may be encountered.

First year ice thickness will average 2.00 m in the southern region and 2.37 m in the north. The first year ice of Arnott and Boyer Straits and Pell Inlet were found to be thinner, averaging 1.80 m. The second year ice of Erskine Inlet will average 2.10 m with the central portion of the Inlet being 10 percent thicker than the northern or southern sections. This was found to be consistent with the historical break-up pattern of Erskine Inlet where the central portion remains longer than the other areas of the Inlet.

The old ice frozen into Byam Martin Channel may be conglomerate floes (ie. comprised of ice of variable ages). This ice will range from 2.50 to 3.50 m with the occasional thickness exceeding 5.65 m (Norland, 1985b).

Break-up usually begins during the last week of July. However, it can occur as early as the second week of July or as late as the third week of August. Fracturing in most years is initiated from Barrow Strait and spreads rapidly throughout Viscount Melville Sound over one to three days. On rare occasions, usually during severe ice years, fracturing will be initiated from M'Clintock Channel. Once fracturing is complete, slumping and loosening of the ice to the south will open a small lead along the south shore of Bathurst Island across the southern consolidated edge of Austin Channel to Byam Martin Island. Fracturing then continues into Austin, Byam and southern Byam Martin Channel to an ice bridge usually between Ile Vanier and Melville Island.

The Byam Martin Channel ice bridge will usually remain until late August to early September. Fracturing of this ice bridge has occurred in seven of the past twelve years. Once the Byam Martin Channel ice bridge has fractured, a high concentration of old ice is free to move out of northern Byam Martin Channel into Parry Channel to the south.

Drift rates are slow out of Byam Martin Channel, averaging one nautical mile per hour. This is due to the weak north to south current in this region. However, strong winds from the prevailing north west will significantly increase the drift rate of ice out of Byam Martin Channel. Conversely, strong south winds will stop and redistribute ice throughout the channel. Winds from the west or east have the additional effect of redirecting the flow of ice away from one side of the channel. These winds also produce the potential for high ice pressures, particularly off the north west coast of Ile Vanier and, to a lesser extent, at the northern entrance of Erskine Inlet.

During warm spring and summer periods, the old ice moving out of Byam Martin Channel is heavily decayed by the time it enters southern Austin Channel. However, old ice in northern Byam Martin Channel will be much less decayed. Generally, the giant old ice floes of Byam Martin Channel rapidly fracture into smaller floe sizes upon entering Austin Channel and Viscount Melville Sound. The extent of old ice decay during the summer period is poorly understood but may have a significant impact on navigation.

Through the months of August and September, there is a gradual widening of the northern Viscount Melville Sound lead to the south and east. M'Clintock Channel remains permanently clogged with ice forming a barrier for any transport of ice through this area. The ice of Viscount Melville Sound usually does not completely melt and leaves a high proportion of old ice in the southern section of the channel. In severe ice years, when a reduced amount of melt occurs, a high concentration of second year ice will occur in southern Viscount Melville Sound the following summer.

Freeze-up begins with new ice formation in northern Byam Martin Channel and western Viscount Melville Sound by mid-September. This thickens to grey-white and thin first year ice by mid-October. Byam Martin, Austin and Byam Channels consolidate by late October or early November. Viscount Melville Sound remains mobile until late November to late January. A lead of younger ice may form under strong north west winds from southern Bathurst Island, across the consolidated ice edge of Austin and Byam Martin Channels to Melville Island. However, this feature is quite sporadic and usually not persistent.

The islands of central Barrow Strait cause a locking up of ice, initiating bridging and consolidation which expands westward into Viscount Melville Sound. A high degree of rubbling and ridging occurs in the ice regime of Viscount Melville Sound due to the ice dynamics at freeze-up. Much less ridging occurs in the ice regime of Byam Martin, Byam and Austin Channels.

3.2.5 Information Deficiencies

The review of ice conditions in the Arctic shows that there is a database available, the size and validity of which is quite varied. It is therefore to be expected that deficiencies will exist. These are described in the following notes.

a) Experience on board the M.V. ARCTIC has shown that the properties of both first year and old ice undergo a dramatic change during the warm spring and summer period. Investigations should be undertaken on the changing properties of ice during this period. Included with this investigation should be an analysis of where decayed ice is more likely and, conversely, less likely to be encountered.

   In addition, the properties of ice of all ages at different times of the year should be quantified. These measured properties should be collected in a manner such that they can be related directly to ship performance and structural requirements.

b) There are many facets of ice regimes which are not presently well understood. Future work should focus on:

   - an understanding of the factors which influence the consolidation and subsequent fracture of ice regimes, particularly in Lancaster Sound,

   - factors which influence the location, development and variability of ice pressure and rubbling,

- ice motion and floe dynamics statistics, which should continue to be collected over the high Arctic.

c) Data collected on ice regimes should relate directly to ship's performance. This should be accomplished by undertaking demonstration projects and dedicated research voyages into ice regimes where data on ships performances do not presently exist.

d) The geographic distribution of glacial ice hazards in the eastern Canadian Arctic are not well understood. Research efforts should focus on quantifying the distribution of icebergs within Baffin Bay. In addition, the seasonal and annual variation of iceberg population should be quantified to investigate the effect, if any, of seasonal and annual climatic fluctuations of iceberg production and decay.

e) The movement of old ice out of Nares Strait into northern Baffin Bay poses a significant threat to navigation at the entrance to Lancaster Sound. Little is known about the pattern and variability of this old ice movement.

f) A reasonable amount of measured ice strength data are available for the Arctic regions, but in most cases the data from different times and locations cannot easily be compared or used to derive reliable design criteria because the results are highly dependent on test conditions. Much more effort is required to establish the conditions under which ice mechanical properties should be measured to develop design criteria.

g) The ice regimes of Baffin Bay, the high Arctic islands and the Beaufort Sea appear to operate independently. A good ice year in one location may occur at the same time as a bad ice year in another. The factors which influence the creation of a good or bad ice year should be investigated to ascertain if predicative models and long range forecasting is feasible.

h) Thousands of useful measurements of ice ridging taken by the AES laser profilometer, have not been analysed or published. Data from most resources including AES, U.S. Navy and other sources, provide misleading information because the ice regimes associated with the ridge data are not defined. The available data should be analysed to present comprehensive information on ridges in a way which is most useful to ship operators and designers.

3.3 Oceanography

3.3.1 General

The major bodies of water and connecting channels are illustrated in Figure 3.2.5. In the eastern Arctic these include Davis Strait, Baffin Bay, Jones Sound, Hudson Strait, Hudson Bay and Foxe Basin. The major channel through the Archipelago is Parry Channel, with connecting channels to the south through McClure Strait, Amundsen Gulf, M'Clintock Channel, Prince of Wales Strait and others. To the west, the Beaufort and Chukchi Seas form a contiguous basin with the Arctic Ocean and are connected with the Pacific via Bering Strait and Bering Sea.

3.3.2 Bathymetry and Soundings

Bathymetric survey is difficult and expensive in the Arctic because of the seasonal or year-round ice cover, darkness, cold temperatures and infrequent ship traffic. Most of the Arctic waterways have not been completely surveyed and are charted from soundings along vessel tracks only. A few anchorages have been surveyed along closely spaced transits to modern standards, while parts of the Beaufort Sea, Parry Channel and Parry Islands areas have been surveyed to modern standards on grids ranging from a few hundred metres to a few kilometres.

Davis Strait and Baffin Bay both have deep water, although Davis Strait forms a sill dividing Baffin Bay from Labrador Sea to the south. Soundings are widely spaced but provide adequate bathymetric information given the depths and regular nature of the seabed offshore. This is not true near most of the coastline which is mountainous, heavily indented by fiords and bays and not completely surveyed.

Baffin Bay terminates to the north at a sill in Smith Sound, which leads to the Arctic Ocean via Nares Strait. Baffin Bay is also contiguous with a shallower basin in Jones Sound and with Lancaster Sound at the east end of Parry Channel.

Hudson Bay and Foxe Basin are both shallow basins connected to Davis Strait via Hudson Strait. Hudson Bay has no other outlet to the sea, while Foxe Basin is connected to channels in the Archipelago via Fury and Hecla Straits at its northwest corner. The coasts of Hudson Bay and Foxe Basin are generally rugged and low lying with higher, plateau areas inland to the east and extreme northwest. Soundings consist of vessel tracks which indicate a regular bottom with depths exceeding 60 metres, and no significant hazard to shipping. Regular soundings are not charted outside of frequently travelled areas and shoals are common along the shores of Hudson Bay; caution should be used when navigating here.

Hudson Strait is a relatively deep channel although most soundings are of a reconnaissance nature and are concentrated along areas of frequent ship traffic. The coastline of Hudson Strait is rugged, with rocky hills rising along the north and southwest shores and fiords indenting the coastline. The southeast side of Hudson Strait consists of Ungava Bay, the south side of which is shallow and not completely charted, with many known shoals.

Most of the large water bodies in and to the north of Parry Channel have been surveyed on a widely-spaced, regular grid which does not adequately portray shoals. Bathymetry is generally regular and depths adequate, with known exceptions including only the limited areas which are shown in Figure 3.3.1.

Passages to the south between Parry Channel and Amundsen Gulf are different from areas already described in that they are shallow and are incompletely sounded. Most of the channels to the west, south and east of Victoria Island are sounded only from reconnaissance surveys or along ship tracks, many shoals are charted and others may exist, and extensive shallows occur. Specific locations which could impede vessel transit are illustrated in Figure 3.3.1.

Widely spaced soundings in McClure Strait show deep water on this passage to the Beaufort Sea, but caution should be used in an uncharted area shown on Figure 3.3.1.

The Beaufort and Chukchi Sea areas include a coastal shelf out to about the 20 metre contour, beyond which the seabed drops to the Arctic basin. The Beaufort Sea includes special, unique bathymetric hazards termed pingoes (CHS, 1932). Pingoes are ice-cored mounds which occur on the seabed due to very localized thickening of permafrost. Hundreds of pingoes have been mapped in the Mackenzie Bay area of the Beaufort Sea where they cause shoaling to 30 percent of the charted depth (CHS, 7651), and uncharted ones are likely present as well. A shipping corridor has been surveyed through the Beaufort Sea to minimize the risk of grounding on pingoes.

Man-made islands cause an additional hazard in the Beaufort Sea where several have been abandoned and are eroding by wave action. Local information should be obtained on the location of existing and abandoned islands before traversing the Mackenzie Bay area.

3.3.3 Currents

Sea currents are an important factor in understanding the distribution and drift of sea ice and patterns of sea surface temperature in the Arctic. Several current systems are present and, while they are not strong enough to impose design constraints on a ship, they do affect the location of shipping routes and then indirectly affect the ice and weather conditions.

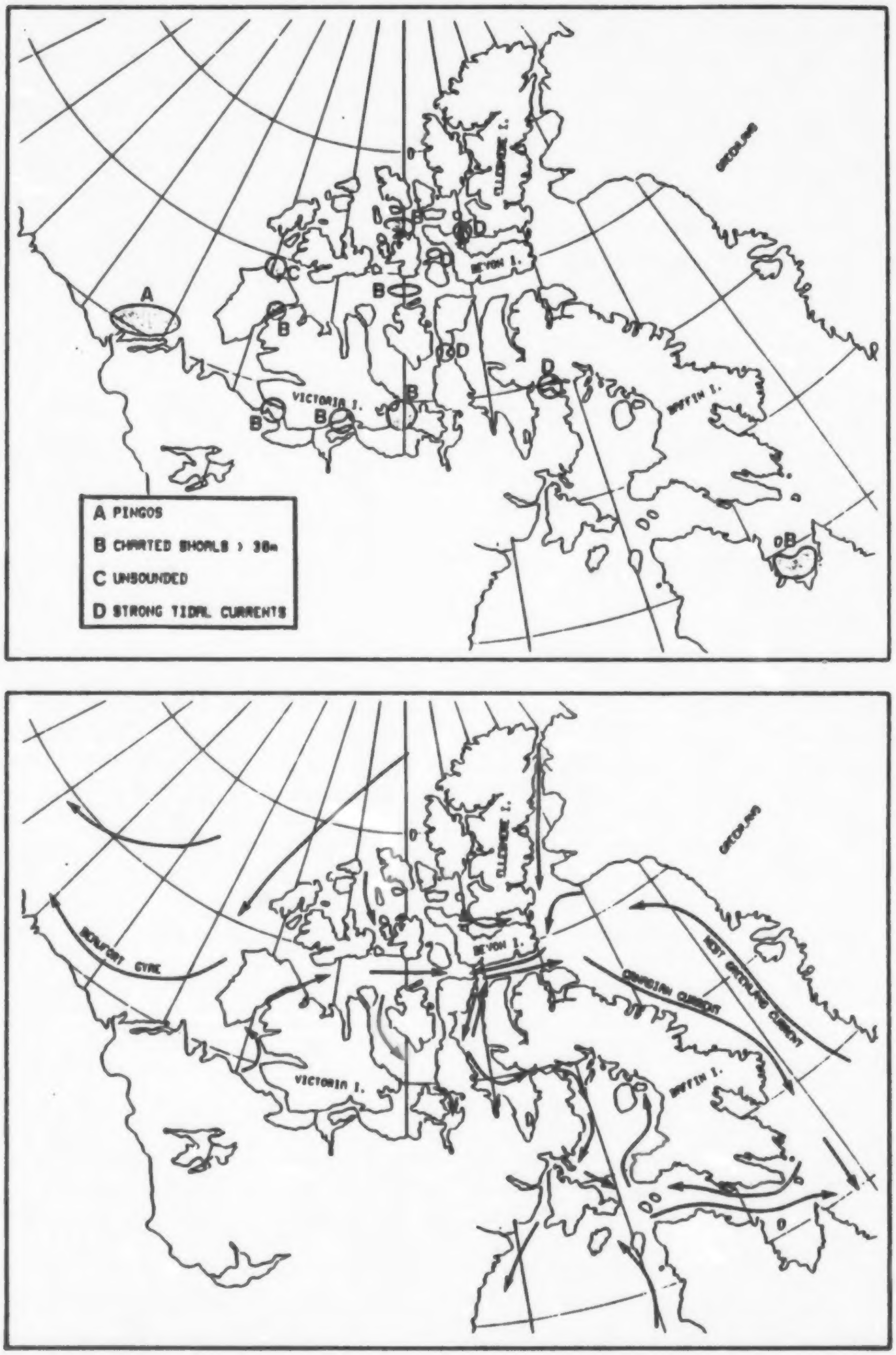
Major surface currents in the Arctic are illustrated in Figure 3.3.1. Water circulation in the Arctic can be categorized in three general areas: western Arctic, Arctic Archipelago and eastern Arctic.

Water to the west of the Archipelago is driven by the Beaufort Gyre which follows the coast in an east to west direction through the Beaufort and Chukchi Seas. Currents in Bering Sea and Bering Strait are more complex, with a net surface flow toward the north through Bearing Strait (Brower, 1977).

Currents in the northern Archipelago are generally weak, but show an overall north west to south east trend, draining through Lancaster Sound and Jones Sound into Baffin Bay. Prince of Wales Strait drains into Amundsen Gulf while other channels to the south of Parry Channel have negligible current (CHS, 1982).

FIGURE 3.3.1

OCEANOGRAPHIC HAZARDS AND SURFACE CURRENTS OF THE CANADIAN ARCTIC


ELLESMERE I.
GREENLAND
DEVON I.
VICTORIA I.
BAFFIN I.
A
B
C
D
A PINGOS
B CHARTED SHOALS > 30m
C UNSOUNDED
D STRONG TIDAL CURRENTS
BEAUFORT GYRE
CANADIAN CURRENT
WEST GREENLAND CURRENT

Water of Baffin Bay and Davis Strait follows an anti-clockwise circuit, flowing to the north along the eastern coastlines and to the south on the west. Arctic water from Nares Strait, Jones Sound and Lancaster Sound joins the southward drift.

Hudson Bay waters also follow an anti-clockwise rotation, draining through Hudson Strait to the Labrador Sea.

Strong tidal currents have been observed in some restricted channels, especially channels in the eastern Arctic which are influenced by the Baffin Bay tides. Dangerous currents outside anchorage areas include:

- Hell Gate and Cardigan Strait (1.5 to 3 knots)
- Bellot Strait (8 knots)
- Labrador Narrows (2 knots)
- Maury Channel (up to 3 knots)
- McDougall Sound (2 knots)

In addition to these channels, several coastal passages and anchorages are subject to strong tidal currents, and Sailing Directions should be consulted before entry.

Tidal measurements in the Chukchi and Bering Sea areas indicate that maximum tidal currents are far less than 1 knot (Mofjeld, 1984) and not hazardous to shipping.

3.3.4 Sea Conditions

Sea state in Arctic regions is less severe than in southern oceans because of limited fetch in the eastern and central Arctic and because the seas are ice covered during the fall and winter stormy seasons. Estimated signficant wave height for a 20 year return period in Baffin Bay is about 6 metres and this decreases westward into the Archipelago (Maxwell, 1980). Twenty year extreme significant wave estimates for the Beaufort Sea range from 6.3 metres in the deep water zone to 3.7 metres at 10 metre water depth. The wave climate becomes more severe in the Alaskan region because of a longer open water season. Twenty five year significant waves in the U.S. Beaufort sea are estimated at 13 metres and increase to 18.5 metres in the Bering Sea (Brower et al, 1977).

An additional effect on water level in shallow areas of the Beaufort, Chukchi and Bering Sea are storm surges. The magnitude of storm surges vary according to local conditions and their frequency is not well known, but studies suggest a twenty five year return period for a 3.6 metre surge in the Canadian Beaufort Sea (Parker, 1983).

The sea surface temperatures can be considered close to freezing through the winter when it is covered by ice. (Freezing temperature of sea water is approximately -1.8°C).

Surface temperatures increase in summer after the ice cover dissipates, with seasonal maxima in August. Measurements show seasonal maxima of about 8°C in Bering Sea, 2.8°C in Chukchi Sea, 1.5°C in Beaufort Sea, 0°C in the Canadian Archipelago, 5°C in Baffin Bay and 8°C in southern Davis Strait.

Significant anomalies in sea surface temperature occur in Baffin Bay. Here, a warm current flows north along the Greenland coast and cold current returns south along Baffin Island and Labrador. This results in a significant difference in surface temperatures and ice conditions across Baffin Bay and Davis Strait, with sea ice forming earlier and persisting later along the cold Canadian coastline. Another anomaly occurs at the north end of Baffin Bay. Here, an upwelling of warmer water maintains the North Water polynya throughout the winter.

The salinity of sea water is approximately 30 to 35 parts per thousand. Salinity is reduced slightly where rivers discharge fresh water into the sea and is also reduced during the ice melt season each year when the surface layer is diluted by melt water.

3.3.5 Ice Accretion

Ice accretion results when water droplets from precipitation or sea spray, strike and freeze to a cold surface on a ship. Most ice accretion on ships is from freezing spray. The availability of spray droplets is controlled mainly by wind speed, and the rate of accretion by air temperature and wind speed. A variety of criteria have been used to predict the severity of ice accretion and these require an air temperature from about -5 to -20°C and wind speed from about 10 to 30 knots.

Ice accretion is not a severe problem in Arctic regions because of the seasonal climate conditions. In summer, air temperatures south of the permanent ice pack are normally above the limits for ice accretion while in winter, the ice cover prevents formation of freezing spray. Severe icing is normally expected in a narrow margin along the southern limits of the ice pack in winter.

3.3.6 Information Deficiencies

The review of Oceanographic conditions has highlighted several information deficiencies. These are described in the following notes.

a) Water depths are reasonably well known at a reconnaissance level for most of the Arctic waters, although shoals have not been well surveyed in most areas. The channels south and east of Victoria Island have many shoal areas and the reconnaissance surveys suggest that deep channels are not available. Additional surveys should be undertaken to establish the best route and sweep for uncharted shoals.

b) Current patterns and variability are poorly documented for the Arctic Archipelago. Consequently, the understanding of ice motion and, particularly, ice modeling will require a much more comprensive data set on currents. Areas of most concern are at the entrance to Lancaster Sound, Barrow Strait, and Viscount Melville Sound.

3.4 Meteorology

3.4.1 General

The climate of Arctic North America is influenced primarily by three pressure systems; an extensive high located over the north west part of the archipelago for much of the year, a low centered on the north east Atlantic and another low centered over the northern Pacific. All of the systems follow an annual cycle related to the ecliptic of the earth, and this is responsible in part for seasonal changes in meteorological conditions.

The polar high is the dominant influence in the western and central Arctic. It is centered over the southern Beaufort Sea in winter and results in the clear skies and cold temperatures which are characteristic of the region. It expands southward and weakens in summer. During the same period, a region of low atmospheric pressure situated over the north Pacific expands northward into the Bearing Sea and is responsible for summer storm tracks across the southern Bering Sea and less often northward into the Beaufort Sea. Infrequently these tracks continue eastward into the Archipelago. Another summer storm track follows the Mackenzie River into the southern Beaufort. This pattern is responsible for the late summer maximum of rainfall and heavy snowfall in the period September to November, in the western Arctic. The influence of the Pacific low is reduced and the Polar high expands to bring clear, cold weather again in early winter.

The dominant influence in the eastern Arctic is the frequency of migratory lows which track from the Labrador Sea and either pass eastward toward Iceland or, alternatively, north into Davis Strait and Baffin Bay. Here, they are blocked by surrounding highlands and gradually die out. These disturbances are most common in fall and winter, when the frequency of occurrence is almost 20 percent (Maxwell, 1980). Disturbances less frequently derive from lows tracking through the central Arctic from the north Pacific region. Large polynyas in the eastern Arctic also generate local, short-lived disturbances.

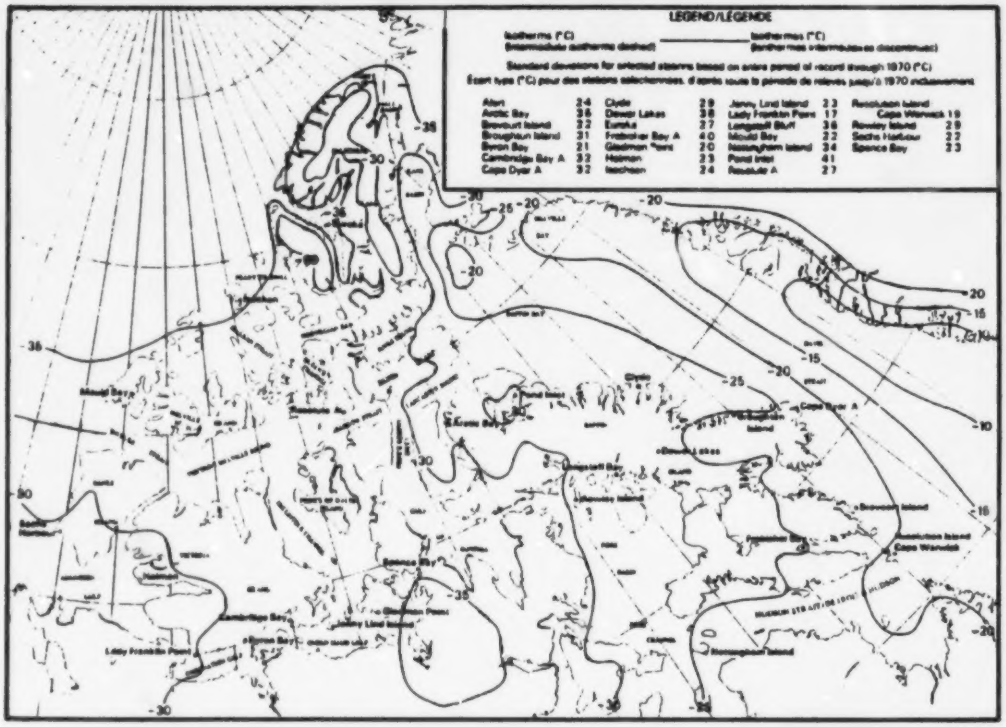
3.4.2 Air Temperature

As shown on Figure 3.4.1, air temperatures in the Arctic region show a distinct spatial and seasonal pattern. Spatially, the lowest temperatures occur in regions under continental influence, either from proximity to the Arctic mainland or to year-round ice cover. The highest winter temperatures occur in Baffin Bay and Davis Strait where the ice cover remains broken year-round and the lowest mean temperatures are found south of the Gulf of Bothnia, due to the continental effect. Summer temperatures follow a more meridional pattern, decreasing gradually toward the north.

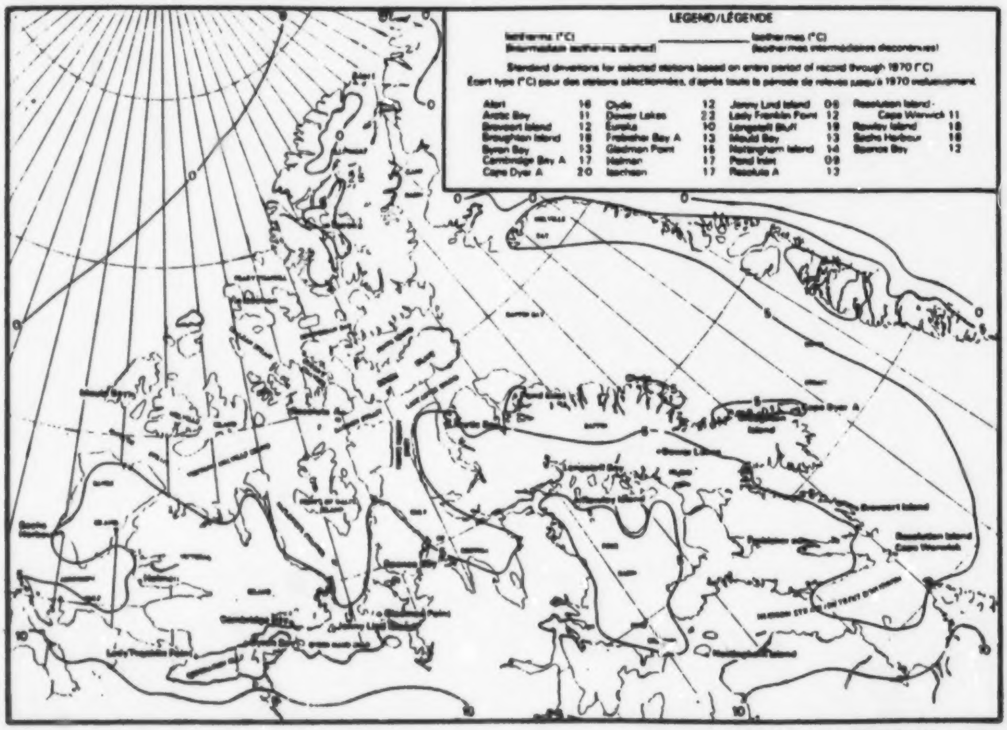
Temperatures generally rise above freezing in late May or early June (CHS, 1982). Temperatures increase rapidly when and where the ice cover is melted but remain below about 5°C where the ice cover persists all summer. Temperatures begin to fall again in late August or early September, and by October mean temperatures are well below freezing.

FIGURE 3.4.1

MEAN AIR TEMPERATURE


LEGEND/LÉGENDE
Isotherms (°C) (Intermediate isotherms dashed)
Isothermes (°C) (Isothermes intermédiaires discontinues)
Standard deviations for selected stations based on entire period of record through 1970 (°C)
Écart type (°C) pour des stations sélectionnées, d'après toute la période de relevés jusqu'à 1970 inclusivement
Alert 24
Arctic Bay 36
Brevoort Island 22
Broughton Island 31
Byron Bay 21
Cambridge Bay A 32
Cape Dyer A 32
Clyde 29
Dewar Lakes 38
Eureka 27
Frobisher Bay A 40
Gladman Point 20
Holman 23
Isachsen 24
Jenny Lind Island 23
Lady Franklin Point 17
Longstaff Bluff 36
Mould Bay 22
Nottingham Island 34
Pond Inlet 41
Resolute A 27
Resolution Island - Cape Warwick 19
Rowley Island 29
Sachs Harbour 22
Spence Bay 23
-35
-30
-25
-20
-15
-10
Cape Dyer A
Cape Warwick
Lady Franklin Point
Byron Bay
Cambridge Bay
Spence Bay
Mould Bay

JANUARY
(DEG. C)


LEGEND/LÉGENDE
Isotherms (°C) (Intermediate isotherms dashed)
Isothermes (°C) (Isothermes intermédiaires discontinues)
Standard deviations for selected stations based on entire period of record through 1970 (°C)
Écart type (°C) pour des stations sélectionnées, d'après toute la période de relevés jusqu'à 1970 inclusivement
Alert 16
Arctic Bay 11
Brevoort Island 12
Broughton Island 18
Byron Bay 13
Cambridge Bay A 17
Cape Dyer A 20
Clyde 12
Dewar Lakes 23
Eureka 10
Frobisher Bay A 13
Gladman Point 16
Holman 17
Isachsen 17
Jenny Lind Island 08
Lady Franklin Point 12
Longstaff Bluff 19
Mould Bay 13
Nottingham Island 14
Pond Inlet 09
Resolute A 13
Resolution Island - Cape Warwick 11
Rowley Island 18
Sachs Harbour 18
Spence Bay 12
0
5
10
Cape Dyer A
Cape Warwick
Lady Franklin Point

JULY
(DEG. C)

3.4.3 Precipitation

Snow cover persists in the Arctic for much of the year but it is not an area of heavy snowfall. Precipitation is varied, being relatively high in eastern areas of cyclonic activity and low in the north west where the Arctic high predominates. Mean annual snow accumulation ranges from less than 50 cm in the southwestern Arctic to about 300 cm in the east. Depths are relatively uniform in the western Arctic but vary widely in the east due to local open water and orographic effects (Maxwell, 1980).

Most of the snowfall occurs in the fall when cyclonic activity is high and the oceans are not yet ice covered. For this reason, snow accumulation on ice covered sea surfaces is likely to be less than that on adjacent land surfaces, particularly in Baffin Bay and Davis Strait where the ocean surface may be open through November. Snow is redistributed by winds through the winter, and the accumulation depth is likely to be more a reflection of local influences on wind transport of fallen snow than of snowfall. The likely result is that snow depths in wide channels of the Archipelago will be less than that at observing stations, while snow depths will be higher in the lee of topographic obstructions near shore.

Rainfall accounts for roughly half the total precipitation amount in the southern Arctic but decreases toward the north and makes up only about 12 percent of the total at Alert (Maxwell, 1980). Much of the total rainfall occurs as drizzle during summer months.

3.4.4 Visibility

Marine visibility in the Arctic is affected primarily by three phenomena: advection fog, steam fog and blowing snow (CHS, 1982).

Advection fog is common during summer months and occurs when a warm air mass is cooled below the dew point when it passes over cold water or sea ice. It is widespread during the ice melt season and tends to be restricted along the ice edge as open water becomes prevalent. Hudson Strait has a very high incidence of advection fog. Steam fog occurs when cold air passes over open water. It is therefore localized over polynyas and along the southern ice edge and is prevalent only in winter.

Blowing snow is a significant factor in winter visibility. Depending on grain size and compaction, snow begins to drift at wind speeds of 8 to 17 knots; at 35 knots, visibility is limited to a few metres in almost all cases. In summer, drizzle or light rain occurs on average one day in three (CHS, 1982) but does not restrict visibility as severely as blowing snow in winter.

3.4.5 Wind

Wind plays an important role in the short term distribution and movement of ice in the Canadian Arctic. For example, wind is more of an important factor effecting ice distribution and movement in the Byam Martin Channel and Viscount Melville Sound area than in Lancaster Sound and Baffin

Bay. Strong wind activity, particularly from the west and north west, in the July time period is likely a contributing factor to the fracturing of Barrow Strait and points west (Canarctic, 1986a).

During the summer open water period, wind will greatly effect the movement of ice. During freeze-up, strong winds will create thinner ice types and open water leads along lee facing land masses and ice ridges. Wind has also been found to be the most important factor in the formation and maintenance of polynyas and flaw leads.

Wind can also create ice pressure at critical locations. Such areas as the entrance to Admiralty and Navy Board Inlets and the south coast of Bylot Island can experience extreme ice pressures when north east winds combine with the existing east flowing current to create high pressure conditions under eight to nine plus tenths ice conditions. Other areas where wind can create high ice pressure are at the entrance to Wellington Channel, southern McDougall Sound and Resolute Passage, the north west tip of Ile Vanier in Byam Martin Channel and, to a lesser extent, the north end of Erskine Inlet.

3.4.6 Information Deficiencies

The review of meteorological conditions has highlighted an information deficiency.

Wind and temperature influences on ice regimes are often difficult to quantify due to the lack of adequate data on these conditions over the Arctic. A programme of comprehensive weather data collection such as employing remote automatic systems should be undertaken. In addition, a wide body of weather data collected by shipboard observations should be continued and expanded.

3.5 Route Specific Environmental Criteria

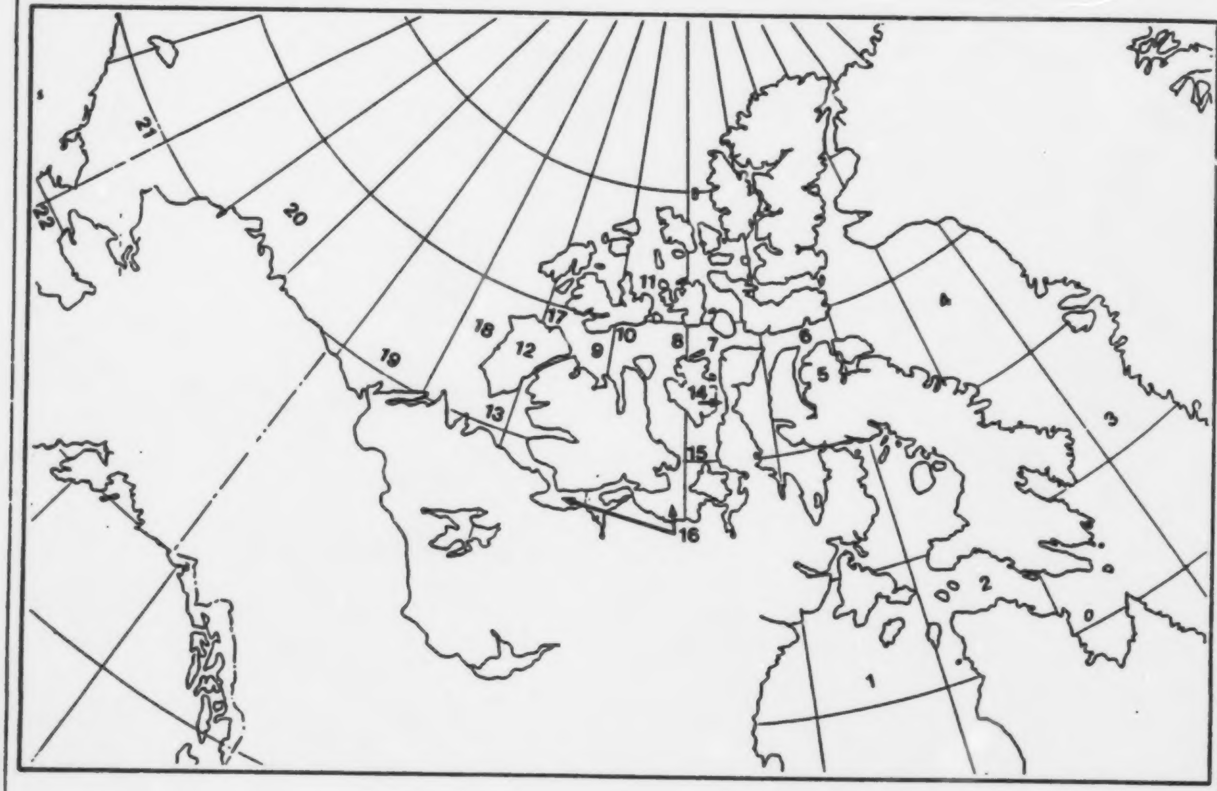
Environmental data are presented in Tables 3.5.1 to 3.5.22 which are specific to a particular location and season and which allow route specific criteria to be defined. Data are presented for the ship routing areas shown in Figure 3.5.1. The overall routes were defined according to probable scenarios for Arctic shipping to the year 2000 and specific route segments were defined on the basis of uniform ice and other environmental conditions.

As has been described above, the magnitudes of environmental factors in the Arctic vary dramatically in nature and most have been measured accurately for only a short period of time and at a limited grid density. As a result, probabilistic design values cannot be defined for most of the parameters used and, instead, extreme measured or average values are used depending on the parameter considered. The data tables should be considered as provisional and should be updated as new information become available.

The relevant parameters are listed and defined in Table 3.5.23.

FIGURE 3.5.1

SHIP ROUTING AREAS



1. HUDSON BAY
2. HUDSON STRAIT
3. DAVIS STRAIT
4. BAFFIN BAY
5. ADMIRALTY INLET
6. LANCASTER SOUND
7. BARROW STRAIT
8. EASTERN VISCOUNT MELVILLE SOUND
9. WESTERN VISCOUNT MELVILLE SOUND
10. BRIDPORT INLET
11. BYAM MARTIN CHANNEL TO LOUGHEED ISLAND
12. PRINCE OF WALES STRAIT
13. AMUNDSEN GULF
14. PEEL SOUND AND FRANKLIN STRAIT
15. LARSEN SOUND AND VICTORIA STRAIT
16. QUEEN MAUD GULF AND CORONATION GULF
17. M'CLURE STRAIT
18. WEST COAST BANKS ISLAND
19. CANADIAN BEAUFORT SEA
20. U.S. BEAUFORT SEA
21. CHUKCHI SEA
22. BERING SEA

TABLE 3.5.1

ENVIRONMENTAL DESIGN CRITERIA

HUDSON BAY

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	100	100	-
Open Pack	-	-	-	-	-	-
Close Pack	-	-	50	-	-	-
Consolidated	100	100	50	-	-	100
FIRST YEAR ICE;						
Thickness {m}	1.45	1.55	0.55	-	-	0.95
Strength -						
Flexural {kPa}	470	420	150	-	-	450
Compressive {MPa}	2.8	2.5	0.9	-	-	2.7
OLD ICE CONCENTRATION	-	-	-	-	-	-
ICEBERG POPULATION	5	10	10	10	5	5
RIDGING FREQUENCY {1/km}	3	5	5	-	-	11
SNOW COVER {m}	0.6	0.6	0.03	-	0.25	0.45
AIR TEMPERATURES;						
Mean {°C}	-29	-16	2	1	-18	-30
Extreme Minimum {°C}	-51	-39	-16	-17	-41	-53
Wind Chill {Class}	VI	IV	II	III	VI	VII
VISIBILITY {%};						
.0 - .8 km	9	5	4	5	9	7
.8 - 4.8 km	11	8	5	6	11	12
4.8 - 10.0 km	80	87	91	89	80	81
Daylight Hours	9	15	18	13	6	5
ICING POTENTIAL	-	-	-	-	Heavy	-

TABLE 3.5.2

ENVIRONMENTAL DESIGN CRITERIA

HUDSON STRAIT

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%}						
Open Water	-	-	-	100	100	-
Open Pack	-	-	-	-	-	-
Close Pack	-	-	100	-	-	-
Consolidated	100	100	-	-	-	100
FIRST YEAR ICE;						
Thickness {m}	1.65	1.75	1.30	-	-	1.15
Strength -						
Flexural {kPa}	620	490	150	-	-	610
Compressive {MPa}	3.7	2.9	0.9	-	-	3.6
OLD ICE CONCENTRATION	-	-	-	-	-	-
ICEBERG POPULATION	-	-	-	-	-	-
RIDGING FREQUENCY {1/km}	2	4	6	-	-	5
SNOW COVER {m}	0.60	0.60	0.04	-	0.25	0.45
AIR TEMPERATURES;						
Mean {°C}	-18	-10	0	2	- 6	-17
Extreme Minimum {°C}	-36	-26	- 9	-10	-23	-38
Wind Chill {Class}	VI	IV	II	III	VI	VII
VISIBILITY {%};						
.0 - .8 km	3	9	20	15	3	3
.8 - 4.8 km	17	14	15	15	15	14
4.8 - 10.0 km	80	77	65	70	82	83
Daylight Hours	9	15	18	12	6	6
ICING POTENTIAL	-	-	-	-	Heavy	-

TABLE 3.5.3

ENVIRONMENTAL DESIGN CRITERIA

DAVIS STRAIT

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE (%);						
Open Water	2	14	51	87	31	18
Open Pack	-	-	9	13	57	-
Close Pack	98	86	40	-	12	82
Consolidated	-	-	-	-	-	-
FIRST YEAR ICE;						
Thickness (m)	1.15	1.35	1.30	-	0.45	0.95
Strength -						
Flexural (kPa)	540	470	150	-	510	520
Compressive (MPa)	3.2	2.8	0.9	-	2.4	3.1
OLD ICE CONCENTRATION	Trace	Trace	Trace	-	-	Trace
ICEBERG POPULATION	100	150	150	150	150	50
RIDGING FREQUENCY (1/km)	8.8	4.4	11.2	3.7	0.2	1.0
SNOW COVER (m)	0.40	0.45	0.05	-	0.25	0.45
AIR TEMPERATURES;						
Mean (°C)	-25	-17	- 1	- 2	-15	-23
Extreme Minimum (°C)	-43	-33	-12	-14	-31	-42
Wind Chill (Class)	VI	IV	II	II	V	VI
VISIBILITY (%);						
.0 - .8 km (%)	3	9	20	15	3	3
.8 - 4.8 km (%)	17	14	15	15	15	14
> 4.8 km (%)	80	77	65	70	82	83
Daylight Hours	9	16	21	12	5	3
ICING POTENTIAL	-	-	-	Moderate	Heavy	-

TABLE 3.5.4

ENVIRONMENTAL DESIGN CRITERIA

BAFFIN BAY

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	58	-	-
Open Pack	-	-	20	42	-	-
Close Pack	100	100	80	-	100	100
Consolidated	-	-	-	-	-	-
FIRST YEAR ICE;						
Thickness {m}	1.45	1.85	1.60	-	0.65	1.05
Strength -						
Flexural {kPa}	600	500	150	-	440	560
Compressive {MPa}	3.6	3.0	0.9	-	2.7	3.4
OLD ICE CONCENTRATION	3/10	Trace	Trace	-	3/10	3/10
ICEBERG POPULATION	50	200	1,000	500	300	100
RIDGING FREQUENCY {1/km}	6	6	6	-	-	6
SNOW COVER {m}	0.4	0.4	0.05	-	0.25	0.4
AIR TEMPERATURES;						
Mean {°C}	-28	-18	1	- 1	-17	-27
Extreme Minimum {°C}	-47	-41	-17	-16	-35	-46
Wind Chill {Class}	VI	IV	II	III	V	VI
VISIBILITY {%};						
.0 - .8 km	3	9	20	15	3	3
.8 - 4.8 km	17	14	15	15	15	14
4.8 - 10.0 km	80	77	65	70	82	83
Daylight Hours	7	18	24	13	8	0
ICING POTENTIAL	-	-	-	Moderate	High	-

TABLE 3.5.5

ENVIRONMENTAL DESIGN CRITERIA

ADMIRALTY INLET

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	7	100	-	-
Open Pack	-	-	52	-	-	-
Close Pack	30	30	-	-	35	30
Consolidated	70	70	41	-	65	70
FIRST YEAR ICE;						
Thickness {m}	1.55	1.95	1.60	-	0.75	1.15
Strength -						
Flexural {kPa}	630	520	150	-	510	570
Compressive {MPa}	3.8	3.1	0.9	-	3.0	3.4
OLD ICE CONCENTRATION	-	-	-	-	-	-
ICEBERG POPULATION	-	-	-	-	-	-
RIDGING FREQUENCY {1/km}	1	1	1	-	-	1
SNOW COVER {m}	0.40	0.40	0.03	-	0.25	0.27
AIR TEMPERATURES;						
Mean {°C}	-31	-20	2	- 2	-22	-30
Extreme Minimum {°C}	-49	-43	-12	-15	-41	-47
Wind Chill {Class}	V	III	II	II	V	V
VISIBILITY {%};						
.0 - .8 km	1	2	-	2	2	1
.8 - 4.8 km	18	14	6	14	23	28
4.8 - 10.0 km	81	84	94	84	75	71
Daylight Hours	7	18	24	13	0	0
ICING POTENTIAL	-	-	-	Moderate	Moderate	-

TABLE 3.5.6

ENVIRONMENTAL DESIGN CRITERIA

LANCASTER SOUND

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE (%);						
Open Water	-	-	78	100	-	-
Open Pack	-	4	3	-	-	-
Close Pack	57	67	8	-	100	100
Consolidated	43	29	11	-	-	-
FIRST YEAR ICE;						
Thickness (m)	1.65	1.95	1.85	-	0.75	1.15
Strength -						
Flexural (kPa)	640	560	150	-	520	620
Compressive (MPa)	3.8	3.4	0.9	-	3.1	3.7
OLD ICE CONCENTRATION	3/10	3/10	-	-	3/10	3/10
ICEBERG POPULATION	10	10	100	100	50	20
RIDGING FREQUENCY (1/km)	4.0	7.0	5.8	-	5.0	4.5
SNOW COVER (m)	0.40	0.40	0.03	-	0.25	0.40
AIR TEMPERATURES;						
Mean (°C)	-33	-23	- 1	- 5	-25	-32
Extreme Minimum (°C)	-52	-42	-17	-21	-43	-52
Wind Chill (Class)	VI	IV	II	III	V	VI
VISIBILITY (%);						
.0 - .8 km	7	4	12	8	4	9
.8 - 4.8 km	36	26	20	15	29	31
4.8 - 10.0 km	57	70	68	77	67	60
Daylight Hours	6	19	24	13	0	0
ICING POTENTIAL	-	-	-	Moderate	Moderate	-

TABLE 3.5.7

ENVIRONMENTAL DESIGN CRITERIA

BARROW STRAIT

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	33	-	-
Open Pack	-	-	-	26	-	-
Close Pack	-	-	-	41	100	30
Consolidated	100	100	100	-	-	70
FIRST YEAR ICE;						
Thickness {m}	1.75	1.95	2.05	-	0.85	1.55
Strength -						
Flexural {kPa}	640	570	115	-	530	640
Compressive {MPa}	3.9	3.4	0.9	-	3.2	3.8
OLD ICE CONCENTRATION	3/10	3/10	3/10	3/10	3/10	3/10
ICEBERG POPULATION	-	-	-	-	-	-
RIDGING FREQUENCY {1/km}	4.0	7.0	5.8	-	5.0	5.0
SNOW COVER {m}	0.27	0.4	0.02	0.07	0.25	0.27
AIR TEMPERATURES;						
Mean {°C}	-33	-23	- 1	- 5	-25	-32
Extreme Minimum {°C}	-52	-42	-17	-21	-43	-52
Wind Chill {Class}	VII	V	III	IV	VI	VII
VISIBILITY {%};						
.0 - .8 km	8	4	12	8	4	9
.8 - 4.8 km	36	26	20	15	29	31
4.8 - 10.0 km	56	70	68	77	67	60
Daylight Hours	6	19	24	13	0	0
ICING POTENTIAL	-	-	-	Heavy	-	-

TABLE 3.5.8

ENVIRONMENTAL DESIGN CRITERIA

EASTERN VISCOUNT MELVILLE SOUND

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	-	-	-
Open Pack	-	-	-	-	-	-
Close Pack	-	-	-	100	54	-
Consolidated	100	100	100	-	46	100
FIRST YEAR ICE;						
Thickness {m}	1.85	1.95	2.05	-	0.85	1.55
Strength -						
Flexural {kPa}	640	580	150	-	550	640
Compressive {MPa}	3.9	3.5	0.9	-	3.3	3.8
OLD ICE CONCENTRATION	6/10	6/10	6/10	6/10	9/10	6/10
ICEBERG POPULATION	1	1	1	1	1	1
RIDGING FREQUENCY {1/km}	4	7	6	3	5	5
SNOW COVER {m}	0.23	0.28	0.03	0.08	0.18	0.23
AIR TEMPERATURES;						
Mean {°C}	-35	-24	0	- 6	-26	-33
Extreme Minimum {°C}	-49	-41	-16	-24	-43	-52
Wind Chill {Class}	VII	V	III	IV	VI	VII
VISIBILITY {%};						
.0 - .8 km	8	4	9	10	7	9
.8 - 4.8 km	36	26	9	15	30	31
4.8 - 10.0 km	56	70	82	75	63	60
Daylight Hours	6	19	24	13	0	0
ICING POTENTIAL	-	-	-	Heavy	-	-

TABLE 3.5.9

ENVIRONMENTAL DESIGN CRITERIA

WESTERN VISCOUNT MELVILLE SOUND

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	-	-	-
Open Pack	-	-	-	-	-	-
Close Pack	-	-	-	100	-	-
Consolidated	100	100	100	-	100	100
FIRST YEAR ICE;						
Thickness {m}	1.75	1.85	1.85	-	0.85	1.55
Strength -						
Flexural {kPa}	640	570	150	-	550	640
Compressive {MPa}	3.9	3.4	0.9	-	3.3	3.8
OLD ICE CONCENTRATION	9/10	9/10	9/10	9/10	9/10	9/10
ICEBERG POPULATION	1	1	1	1	1	1
RIDGING FREQUENCY {1/km}	6	6	11	-	6	11
SNOW COVER {m}	0.23	0.23	0.03	0.08	0.18	0.23
AIR TEMPERATURES;						
Mean {°C}	-35	-24	0	- 6	-26	-33
Extreme Minimum {°C}	-49	-41	-16	-24	-43	-52
Wind Chill {Class}	VII	V	II	III	IV	VII
VISIBILITY {%};						
.0 - .8 km	8	4	9	10	7	8
.8 - 4.8 km	36	26	9	15	30	31
4.8 - 10.0 km	56	70	82	75	63	61
Daylight Hours	6	19	24	13	0	0
ICING POTENTIAL	-	-	-	Heavy	-	-

TABLE 3.5.10

ENVIRONMENTAL DESIGN CRITERIA

BRIDPORT INLET

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	-	-	-
Open Pack	-	-	-	-	-	-
Close Pack	-	-	-	100	100	-
Consolidated	100	100	100	-	-	100
FIRST YEAR ICE;						
Thickness {m}	1.85	1.95	2.05	-	0.85	1.55
Strength -						
Flexural {kPa}	640	580	150	-	550	640
Compressive {MPa}	3.9	3.5	0.9	-	3.3	3.8
OLD ICE CONCENTRATION	6/10	6/10	9/10	3/10	9/10	6/10
ICEBERG POPULATION	1	1	1	1	1	1
RIDGING FREQUENCY {1/km}	4	7	6	3	5	5
SNOW COVER {m}	0.23	0.23	0.03	0.08	0.18	0.23
AIR TEMPERATURES;						
Mean {°C}	-35	-24	0	- 6	-26	-33
Extreme Minimum {°C}	-49	-41	-16	-24	-43	-52
Wind Chill {Class}	VII	V	II	IV	VI	VII
VISIBILITY {%};						
.0 - .8 km	8	4	9	10	7	9
.8 - 4.8 km	36	26	9	15	30	31
4.8 - 10.0 km	56	70	82	75	63	60
Daylight Hours	4	22	24	13	0	0
ICING POTENTIAL	-	-	-	Heavy	-	-

TABLE 3.5.11

ENVIRONMENTAL DESIGN CRITERIA

BYAM MARTIN CHANNEL TO LOUGHEED ISLAND

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	-	-	-
Open Pack	-	-	-	-	-	-
Close Pack	-	-	-	70	11	-
Consolidated	100	100	100	30	89	100
FIRST YEAR ICE;						
Thickness {m}	1.85	2.10	2.05	-	0.85	1.55
Strength -						
Flexural {kPa}	640	580	150	-	550	640
Compressive {MPa}	3.9	3.5	0.9	-	3.3	3.8
OLD ICE CONCENTRATION	9/10	9/10	9/10	10/10	10/10	9/10
ICEBERG POPULATION	1	1	1	1	1	1
RIDGING FREQUENCY {1/km}	-	-	-	-	-	-
SNOW COVER {m}	0.23	0.23	0.03	0.08	0.18	0.23
AIR TEMPERATURES;						
Mean {°C}	-35	-24	0	- 6	-26	-33
Extreme Minimum {°C}	-49	-41	-16	-24	-43	-52
Wind Chill {Class}	VII	V	II	IV	VI	VII
VISIBILITY {%};						
.0 - .8 km	6	3	1	10	4	6
.8 - 4.8 km	31	33	17	15	37	25
4.8 - 10.0 km	63	64	82	75	59	69
Daylight Hours	5	20	24	13	0	0
ICING POTENTIAL	-	-	-	Heavy	-	-

TABLE 3.5.12

ENVIRONMENTAL DESIGN CRITERIA

PRINCE OF WALES STRAIT

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	64	-	-
Open Pack	-	-	8	15	-	-
Close Pack	-	-	13	21	35	35
Consolidated	100	100	79	-	65	65
FIRST YEAR ICE;						
Thickness {m}	1.75	1.95	1.60	-	0.75	1.25
Strength -						
Flexural {kPa}	630	520	150	-	470	600
Compressive {MPa}	3.8	3.1	0.9	-	2.8	3.6
OLD ICE CONCENTRATION	3/10	3/10	6/10	6/10	6/10	6/10
ICEBERG POPULATION	-	-	-	-	-	-
RIDGING FREQUENCY {1/km}	-	-	-	-	-	-
SNOW COVER {m}	0.23	0.23	0.03	0.08	0.18	0.23
AIR TEMPERATURES;						
Mean {°C}	-31	-18	4	0	-20	-29
Extreme Minimum {°C}	-46	-40	-11	-15	-39	-44
Wind Chill {Class}	VI	III	II	II	IV	VI
VISIBILITY {%};						
.0 - .8 km	4	2	5	7	3	3
.8 - 4.8 km	22	21	8	12	25	23
4.8 - 10.0 km	74	77	87	81	72	74
Daylight Hours	6	17	24	13	0	0
ICING POTENTIAL	-	-	-	Moderate	Very Heavy	-

TABLE 3.5.13

ENVIRONMENTAL DESIGN CRITERIA

AMUNDSEN GULF

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	18	100	-	-
Open Pack	-	-	20	-	-	-
Close Pack	29	-	11	-	93	80
Consolidated	71	100	51	-	7	20
FIRST YEAR ICE;						
Thickness {m}	1.65	1.75	1.30	-	0.65	1.25
Strength -						
Flexural {kPa}	620	510	150	-	450	600
Compressive {MPa}	3.7	3.1	0.9	-	2.7	3.6
OLD ICE CONCENTRATION	Trace	Trace	-	-	Trace	Trace
ICEBERG POPULATION	-	-	-	-	-	-
RIDGING FREQUENCY {1/km}	3.0	3.0	0.3	-	4.0	3.0
SNOW COVER {m}	0.23	0.23	-	-	0.18	0.23
AIR TEMPERATURES;						
Mean {^{o}C}	-30	-19	2	1	-18	-29
Extreme Minimum {^{o}C}	-47	-39	-12	-13	-37	-47
Wind Chill {Class}	VI	III	II	II	IV	VI
VISIBILITY {%};						
.0 - .8 km	4	2	5	6	3	4
.8 - 4.8 km	22	21	8	16	25	23
4.8 - 10.0 km	74	77	87	78	72	73
Daylight Hours	8	17	24	13	2	0
ICING POTENTIAL	-	-	-	Moderate	Heavy	-

TABLE 3.5.14

ENVIRONMENTAL DESIGN CRITERIA

PEEL SOUND

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	-	-	-
Open Pack	-	-	-	9	-	-
Close Pack	-	-	-	91	-	-
Consolidated	100	100	100	-	100	100
FIRST YEAR ICE;						
Thickness {m}	1.85	1.95	2.05	-	0.85	1.55
Strength						
Flexural {kPa}	650	570	150	-	530	640
Compressive {MPa}	3.9	3.4	0.9	-	3.2	3.8
OLD ICE CONCENTRATION	Trace	3/10	3/10	3/10	3/10	Trace
ICEBERG POPULATION	-	-	-	-	-	-
RIDGING FREQUENCY {1/km}	-	-	-	-	-	-
SNOW COVER {m}	0.23	0.28	0.03	0.08	0.25	0.28
AIR TEMPERATURES;						
Mean {°C}	-33	-23	- 1	- 5	-25	-32
Extreme Minimum {°C}	-52	-42	-17	-21	-43	-52
Wind Chill {Class}	VII	V	II	IV	VI	VII
VISIBILITY {%};						
.0 - .8 km	8	4	8	10	7	9
.8 - 4.8 km	36	26	9	15	30	31
4.8 - 10.0 km	56	70	83	75	63	60
Daylight Hours	7	18	24	13	0	0
ICING POTENTIAL	-	-	-	Heavy	-	-

TABLE 3.5.15

ENVIRONMENTAL DESIGN CRITERIA

LARSON SOUND VICTORIA STRAIT

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	-	-	-
Open Pack	-	-	-	8	-	-
Close Pack	-	-	-	92	-	-
Consolidated	100	100	100	-	100	100
FIRST YEAR ICE;						
Thickness {m}	1.85	1.95	1.60	-	0.85	1.55
Strength -						
Flexural {kPa}	650	550	150	-	520	650
Compressive {MPa}	3.9	3.3	0.9	-	3.1	3.9
OLD ICE CONCENTRATION	3/10	3/10	6/10	3/10	3/10	3/10
ICEBERG POPULATION	1	1	1	1	1	1
RIDGING FREQUENCY {1/km}	6	6	4	-	5	5
SNOW COVER {m}	0.28	0.28	0.03	0.03	0.18	0.23
AIR TEMPERATURES;						
Mean {°C}	-35	-23	1	- 1	-24	-35
Extreme Minimum {°C}	-53	-43	-19	-18	-47	-50
Wind Chill {Class}	VII	V	II	III	VI	VII
VISIBILITY {%};						
.0 - .8 km	7	5	2	7	4	8
.8 - 4.8 km	28	17	8	12	24	29
4.8 - 10.0 km	65	78	90	81	72	63
Daylight Hours	8	17	24	13	2	0
ICING POTENTIAL	-	-	-	Moderate	-	-

TABLE 3.5.16

ENVIRONMENTAL DESIGN CRITERIA

QUEEN MAUD AND CORONATION GULF

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	94	-	-
Open Pack	-	-	-	6	-	-
Close Pack	-	-	-	-	-	-
Consolidated	100	100	100	-	100	100
FIRST YEAR ICE;						
Thickness {m}	1.85	1.95	1.60	-	0.75	1.55
Strength -						
Flexural {kPa}	650	550	150	-	520	640
Compressive {MPa}	3.9	3.3	0.9	-	3.1	3.9
OLD ICE CONCENTRATION	Trace	Trace	3/10	3/10	Trace	Trace
ICEBERG POPULATION	-	-	-	-	-	-
RIDGING FREQUENCY {1/km}	6	6	4	-	5	5
SNOW COVER {m}	0.28	0.40	-	0.03	0.18	0.23
AIR TEMPERATURES;						
Mean {°C}	-34	-22	2	- 1	-24	-34
Extreme Min {°C}	-51	-43	-18	-17	-42	-53
Wind Chill {Class}	VII	V	II	III	VI	VII
VISIBILITY {%};						
.0 - .8 km	7	5	2	7	4	8
.8 - 4.8 km	28	17	8	12	24	28
4.8 - 10.0 km	65	78	90	81	72	64
Daylight Hours	8	17	24	13	2	0
ICING POTENTIAL	-	-	-	Moderate	Heavy	-

TABLE 3.5.17

ENVIRONMENTAL DESIGN CRITERIA

MCCLURE STRAIT

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	-	-	-
Open Pack	-	-	-	-	-	-
Close Pack	8	-	-	100	21	23
Consolidated	92	100	100	-	79	77
FIRST YEAR ICE;						
Thickness {m}	1.75	1.95	1.60	-	0.85	1.55
Strength -						
Flexural {kPa}	650	580	200	-	560	640
Compressive {MPa}	3.9	3.5	1.2	-	3.4	3.9
OLD ICE CONCENTRATION	9/10	9/10	9/10	9/10	9/10	9/10
ICEBERG POPULATION	1	1	1	1	1	1
RIDGING FREQUENCY {1/km}	6	6	11	-	6	11
SNOW COVER {m}	0.23	0.23	0.03	0.08	0.13	0.23
AIR TEMPERATURES;						
Mean {°C}	-35	-24	0	- 7	-27	-34
Extreme Minimum {°C}	-54	-44	-14	-26	-44	-53
Wind Chill {Class}	VII	IV	II	III	VI	VII
VISIBILITY {%};						
.0 - .8 km	6	3	1	10	4	6
.8 - 4.8 km	31	33	17	15	37	25
4.8 - 10.0 km	63	64	82	75	59	69
Daylight Hours	6	19	24	13	0	0
ICING POTENTIAL	-	-	-	Moderate	Heavy	-

TABLE 3.5.18

ENVIRONMENTAL DESIGN CRITERIA

WEST COAST OF BANKS ISLAND

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	10	29	-	-
Open Pack	-	-	-	19	-	-
Close Pack	100	76	73	52	100	100
Consolidated	-	24	17	-	-	-
FIRST YEAR ICE;						
Thickness {m}	1.75	1.95	1.60	-	0.85	1.25
Strength -						
Flexural {kPa}	630	530	150	-	500	620
Compressive {MPa}	3.8	3.2	0.9	-	3.0	3.7
OLD ICE CONCENTRATION	6/10	6/10	6/10	9/10	9/10	6/10
ICEBERG POPULATION	1	1	1	1	1	1
RIDGING FREQUENCY {1/km}	15	15	10	9	10	13
SNOW COVER {m}	0.28	0.23	0.03	0.08	0.18	0.15
AIR TEMPERATURES;						
Mean {°C}	-31	-20	2	- 2	-22	-30
Extreme Minimum {°C}	-49	-40	-17	-23	-43	-52
Wind Chill {Class}	VI	IV	II	III	VI	VII
VISIBILITY {%};						
.0 - .8 km	4	6	9	11	6	5
.8 - 4.8 km	14	12	9	12	22	19
4.8 - 10.0 km	82	82	82	77	72	76
Daylight Hours	7	18	24	13	0	0
ICING POTENTIAL	-	-	-	Moderate	Heavy	-

TABLE 3.5.19

ENVIRONMENTAL DESIGN CRITERIA

CANADIAN BEAUFORT SEA

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	10	81	-	-
Open Pack	-	-	26	19	-	-
Close Pack	69	29	33	-	100	100
Consolidated	31	71	31	-	-	-
FIRST YEAR ICE;						
Thickness {m}	1.65	1.75	1.30	-	0.65	1.15
Strength -						
Flexural {kPa}	610	500	150	-	460	580
Compressive {MPa}	3.7	3.0	0.9	-	2.8	3.5
OLD ICE CONCENTRATION	Trace	Trace	Trace	-	Trace	Trace
ICEBERG POPULATION	1	1	1	1	1	1
RIDGING FREQUENCY {1/km}	8	12	7	-	7	12
SNOW COVER {m}	-	-	-	-	-	-
AIR TEMPERATURES;						
Mean {°C}	-29	-17	5	1	-20	-28
Extreme Minimum {°C}	-50	-42	-11	-12	-39	-49
Wind Chill {Class}	VI	IV	II	III	VI	VII
VISIBILITY {%};						
.0 - .8 km	6	3	8	11	6	6
.8 - 4.8 km	14	13	7	15	16	14
4.8 - 10.0 km	80	84	85	74	78	80
Daylight Hours	7	18	24	13	0	0
ICING POTENTIAL	-	-	-	Moderate	Heavy	-

TABLE 3.5.20

ENVIRONMENTAL DESIGN CRITERIA

AMERICAN BEAUFORT SEA

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	-	10	-	-
Open Pack	-	-	-	90	-	-
Close Pack	-	-	85	-	100	-
Consolidated	100	100	15	-	-	100
FIRST YEAR ICE;						
Thickness {m}	1.86	2.01	-	-	0.80	1.43
Strength -						
Flexural {kPa}	610	520	-	-	450	570
Compressive {MPa}	3.7	3.1	-	-	2.7	3.4
OLD ICE CONCENTRATION	3/10	3/10	3/10	3/10	3/10	3/10
ICEBERG POPULATION	1	1	1	1	1	1
RIDGING FREQUENCY {1/km}	12	11	-	-	2	12
SNOW COVER {m}	-	-	-	-	-	-
AIR TEMPERATURES;						
Mean {°C}	-29	-19	2	0	-18	-25
Extreme Minimum {°C}	-44	-32	- 6	- 6	-34	-42
Wind Chill {Class}	DNA	DNA	DNA	DNA	DNA	DNA
VISIBILITY {%};						
.0 - .8 km	9	13	14	18	11	15
.8 - 4.8 km	25	39	30	42	33	39
4.8 - 10.0 km	66	48	56	40	56	46
Daylight Hours	6	14	19	10	0	0
ICING POTENTIAL	DNA	DNA	DNA	DNA	DNA	DNA

DNA: Data Not Available

TABLE 3.5.21

ENVIRONMENTAL DESIGN CRITERIA

CHUKCHI SEA

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	-	-	4	100	-	-
Open Pack	-	-	62	-	14	-
Close Pack	100	100	34	-	86	-
Consolidated	-	-	-	-	-	100
FIRST YEAR ICE;						
Thickness {m}	1.52	1.65	-	-	0.60	1.13
Strength -						
Flexural {kPa}	550	500	-	-	400	490
Compressive {MPa}	3.3	3.0	-	-	2.4	2.9
OLD ICE CONCENTRATION	-	-	-	-	-	-
ICEBERG POPULATION	-	-	-	-	-	-
RIDGING FREQUENCY {1/km}	8	6	-	-	4	4
SNOW COVER {m}	-	-	-	-	-	-
AIR TEMPERATURES;						
Mean {°C}	-24	-17	2	2	-13	-20
Extreme Minimum {°C}	-42	-32	- 6	- 6	-32	-40
Wind Chill {Class}	DNA	DNA	DNA	DNA	DNA	DNA
VISIBILITY {%};						
.0 - .8 km	6	6	10	5	6	5
.8 - 4.8 km	23	20	28	29	21	20
4.8 - 10.0 km	71	74	62	66	73	75
Daylight Hours	7	13	17	10	4	4
ICING POTENTIAL	DNA	DNA	DNA	DNA	DNA	DNA

DNA: Data Not Available

TABLE 3.5.22

ENVIRONMENTAL DESIGN CRITERIA

BERING SEA

PARAMETERS	FEB-MAR	APR-MAY	JUN-JLY	AUG-SEP	OCT-NOV	DEC-JAN
ICE COVERAGE {%};						
Open Water	10	-	100	100	100	33
Open Pack	-	29	-	-	-	-
Close Pack	23	58	-	-	-	67
Consolidated	67	13	-	-	-	-
FIRST YEAR ICE;						
Thickness {m}	1.27	1.34	-	-	0.46	0.97
Strength -						
Flexural {kPa}	390	300	-	-	150	300
Compressive {MPa}	2.3	1.8	-	-	0.9	1.8
OLD ICE CONCENTRATION	-	-	-	-	-	-
ICEBERG POPULATION	-	-	-	-	-	-
RIDGING FREQUENCY {1/km}	11	7.5	-	-	-	-
SNOW COVER {m}	-	-	-	-	-	-
AIR TEMPERATURES;						
Mean {°C}	- 9	- 5	5	7	- 2	- 7
Extreme Minimum {°C}	-34	-26	- 2	- 2	-20	-32
Wind Chill {Class}	DNA	DNA	DNA	DNA	DNA	DNA
VISIPILITY {%};						
.0 - .8 km	24	18	16	15	1	15
.8 - 4.8 km	43	32	25	22	17	54
4.8 - 10.0 km	33	50	59	63	82	31
Daylight Hours	7	13	18	13	8	6
ICING POTENTIAL	DNA	DNA	DNA	DNA	DNA	DNA

DNA: Data Not Available

TABLE 3.5.23

ENVIRONMENTAL PARAMETERS
(Used In Tables 1 to 22)

- sea ice concentration: the percent of route distance travelled thorugh each category of ice concentration and ice type.
- ice thickness: the mean thickness of month's end, in centimetres
- snow cover: the mean thickness at month's end, in centimetres.
- flexural strength: representative mean value, in megapascals.
- compressive strength: representative mean value, in megapascals.
- ridging frequency: mean frequency along ship track, per kilometre.
- iceberg population: estimated mean frequency of icebergs 100 metres or more in diameter, per 2° latitude/4° longitude cell.
- air temperature: in °C based on Normals 1951-80.
- windchill: Occurrence of wind chill classes
- visibility: exceedence of visibility ranges.
- daylight hours: duration of daylight (not including twilight).
- icing potential: Occurence of ice accretion potential.

4. SHIP OPERATIONS

4.1 Introduction

The operation of ships in Arctic waters can be said to have begun in earnest in the 17th Century with the northern whaling industry. However, little in the way of technological advancement was made until natural resources were discovered and exploitation was planned in the 1970's. Until this time, shipping in the Arctic was confined to the summer "open water" season for the resupply of isolated communities and government outposts.

The Arctic Pilot Project, begun in the early 1970's, generated a surge of research into all aspects of Commercial Arctic Shipping. More recently, the extended season operation of the M.V. ARCTIC has provided valuable operational experience in Arctic waters and has demonstrated the direction and need for further research into commercial vessel operations.

The operation of ships in the Arctic covers a wide range of subjects. Technological advances are the means by which operations will become both safe and practical.

This section will review the available data pertaining to Arctic Ship Operations and will draw conclusions regarding both the present state of knowledge and regulation.

4.2 Safety

4.2.1 General

The safe passage of ships has been essential to commerce since the first waterborne venture and it is natural that governments and international organizations have involved themselves deeply in the subject. Here in Canada, the Canada Shipping Act contains the bulk of safety regulations for ships.

The I.M.O. (International Maritime Organization), of which Canada is a signatory member, has a special responsibility for the safety of life at sea. As a signatory member to the International Convention for the Safety of Life at Sea (SOLAS 1974) Canada abides by the conventions regulations. These regulations apply to all vessels of signatory nations, whether or not they trade in Arctic waters. Amendments to these regulations were made in 1981 and 1983 and will soon be ratified by Canada. However, within SOLAS there are few considerations given to the ultra cold conditions that can occur in the Arctic winter.

There is a wealth of literature dealing with personnel and vessel safety but there is very little that is pertinent when it comes to Arctic safety.

4.2.2 Vessel Safety

Vessel safety, from the operations viewpoint, relates to the functions and potential problems related to a major fire or to the need for damage repair or salvage in the event of a collision with another vessel or ice feature. The practical problems which will arise in these situations in a cold environment are quite different than if the environment was more temperate.

An example of the consequences are illustrated by the HUDSON TRANSPORT disaster when a major fire occurred in December in very cold conditions in the St. Lawrence River. It was found to be impossible, for several reasons, for the crew to effectively fight the fire. Similarly, repairs to vessels in the Beaufort Sea, such as the propeller blade replacement on the CANMAR KIGORIAK, have been achieved but with great difficulty.

4.2.2.1 Firefighting

Research of the regulations of the IMO and various countries, who could be expected to have introduced legislation pertaining directly to fire protection and extinguishing equipment for use in sub-zero temperatures, has revealed that little attention has been focussed on the subject. Any references made to cold temperature conditions are vague and give little guidance beyond the phrase "shall be protected from freezing". The Canadian Fire Protection, Detection and Extinguishing Regulations are more specific than other countries in this respect but, even so, do not go far enough (Melville, 1985b).

Table 4.2.1 presents a comparison of the SOLAS regulations which allude specifically to cold temperatures, and those of Canada, Norway, the United Kingdom and the USA. From this table it can be easily seen that the regulations offer little guidance in cold temperature shipboard firefighting.

The Marine Emergency Duties (MED) course syllabus, which forms part of the Canada Shipping Act, makes little reference to Arctic conditions as they affect firefighting, nor have any guidelines been identified.

Firefighting, especially under Arctic winter conditions, can have equipment problems to the extent that it may be impossible to extinguish a fire with current regulatory equipment.

4.2.2.2 Damage Repair and Salvage

The most recent investigations in this area have been completed by Melville (1984). In the event of any damage which results in a fracture of the outer shell plating, the watertight integrity of the ship will be compromised. In this case, the rapid and correct performance of the crew will be paramount if the vessel is to be saved. While double hulled vessels can suffer greater damage before their watertight integrity is compromised, there would still be concern over the structural integrity of the vessel.

TABLE 4.2.1
COMPARISON OF REGULATORY COLD TEMPERATURE REFERENCES

	SOLAS	CANADA	U.S.A.	NORWAY	UNITED KINGDOM
Portable Fire Extinguishers	As approved by (Ref. 6) the Administration.	Extinguishers other (Sch. III) than water pump type not to be installed in areas where temp. is below -40ºC or as specified on extinguisher label. Water, soda acid and foam types not be be installed in areas where temp. is below 4º except where plain water types are protected by adding appropriate anti-freeze charge.	Hand portable or semi-portable extinguishers which are required on their nameplates to be protected from freezing are not be be located where freezing temps. may be expected.	Extinguishers which may be exposed to frost are to be of frost proof type.	-
Fire Main	Arrangement of (Reg. 4) pipes and hydrants to be such as to avoid possibility of freezing.	The arrangement of (Sch. I) pipes and hydrants are to be such as to avoid the possibility of freezing and drain valves provided as necessary.	All parts of fire main on exposed decks to be protected against freezing or to be fitted with cut-out or drain valves except when closed valves to be sealed open.	As SOLAS	As SOLAS
Fire Hoses	Material to be (Reg. 4) approved by the Administration.	Fire hoses to be of (Sch. I) cotton and/or synthetic fibre, rubber lined or other suitable material and not to be affected by anticipated low temp. conditions.	To be lined commercial type and conform to Underwriters' Laboratory Standard 10 or Federal Specification ZZ-H-451(E).	Material not specified in regulations - to be submitted for approval by the Administration.	To be made of closely woven flax, canvas or other suitable material.
Fixed Fire Extinguishing Systems	GAS - no cold temp. requirements.	GAS - containers are (Sch. IV) not to be located so as to be subject to severe weather conditions and when excessive climatic or mechanical exposures are expected. Suitable guards or enclosures are to be provided.	No cold temperature requirements.	No cold temperature requirements.	No cold temperature requirements.

TABLE 4.2.1 (con't)
COMPARISON OF REGULATORY COLD TEMPERATURE REFERENCES

SOLAS	CANADA	U.S.A.	NORWAY	UNITED KINGDOM
-	CARBON DIOXIDE - Storage temps. to be within a range from -18°C to 54°C for total flooding and 0°C to 49°C for local application unless system is designed for temps. outside these ranges.	-	-	-
-	HALONGENATED HYDROCARBON - Storage temps. to be within a range from -29°C to 55°C for total flooding and 0°C to 55°C for local application unless system is designed for temps. outside these ranges.	-	-	The system shall be designed to operate within the temp. range likely to be experienced.
-	FIXED FOAM - foam solution to be suitable for anticipated low temp. conditions. Controls to be so located that operation of system will not be affected by these temps.	-	-	-
Any part of an (Reg. 12) automatic sprinkler system which may be subjected to freezing temps. in service must be suitably protected.	AUTOMATIC SPRINKLER SYSTEMS* - Any parts of a wet pipe automatic sprinkler system which may be subjected to freezing temps. in service, are to be suitably protected. * Canadian regulations allow for dry pipe automatic sprinkler systems where low temperatures are encountered.	As SOLAS	As SOLAS	It shall be of the wet pipe type but small exposed sections may be of the dry pipe type where in the opinion of the Secretary of State this is a necessary precaution. Any parts of the system which may be subjected to freezing temps. in service shall be suitably protected against freezing.

TABLE 4.2.1 (con't)
COMPARISON OF REGULATORY COLD TEMPERATURE REFERENCES

	SOLAS	CANADA	U.S.A.	NORWAY	UNITED KINGDOM
Emergency Fire Pump	Diesel power (Reg. 4) source to be readily started to a temp. of 0°C. If lower temps. likely to be encountered, consideration to be given to provision of heating.	Diesel power source (Sch. I) to be readily started and operated down to the lowest temp. likely to be encountered. Consideration shall be given to the provision and maintenance of heating arrangements acceptable to the Board, so that ready starting will be assured. Fuel viscosity to be suitable for all operational temps.	-	As SOLAS with additional requirement that the space in which the driving engine is is located is to be heated.	Any diesel driven power source for the emergency fire pump shall be capable of being readily started in its cold condition down to a temp. of 0°C by hand cranking. Where lower temps. likely to be encountered, heating arrangements acceptable to the Secretary of State shall be provided.
Inert Gas System	Provision to be (Reg. 62) made to ensure the water seal is protected against freezing in such a way that the integrity of the seal is not impaired by overheating.	Provision to be (Sch. VII) made to ensure the water seal is protected against freezing in such as way that the integrity of the seal is not impaired by overheating. Where necessary, scrubber and cooling water to be so located or have other methods of protection that operation of the system shall not be affected by anticipated low temperature conditions.	-	As SOLAS	As SOLAS

In the case of global damage, the degree to which the vessel's seaworthiness is affected must be assessed by the crew in order that the appropriate action may be taken. Depending on the extent, hull damage in way of the engine room or pump room could have serious consequences. If the inner hull were to give way it would be vital that damage control procedures be initiated immediately, since pumproom equipment could become inoperable and, if engine room flooding reached a level of main propulsion or generator bearings, it would result in failure of propulsion and electrical machinery and equipment.

Few, if any, facilities exist in the Arctic which could undertake major hull and/or machinery damage repairs to a vessel, such as the ARCTIC, engaged in winter operations. This does not necessarily mean that the ship is helpless, as much would depend on the ship's location and the extent and nature of the damage.

In the central and eastern Arctic, if the vessel can reach Nanisivik or Little Cornwallis Island where mining facilities are located, some assistance may be obtained. In the Beaufort Sea, there are floating drydocks and workshop facilities situated at Tuktoyaktuk and McKinley Bay. These drydocks are only suitable for relatively small ships and are usually inoperable during the winter months.

4.2.3 Personnel Safety

Personnel safety on-board ship is of paramount concern and governments have responded to the need to enforce personnel safety standards. The "Safe Working Practices Regulations" of the Canada Shipping Act apply to all Canadian ships whether in Arctic waters or not, and in the United Kingdom it is required that vessels carry on-board the Department of Trade's booklet "Code of Safe Working Practices for Merchant Seamen".

The regulations which are most closely concerned with ship abandonment are, for a Canadian ship trading internationally, the Canada Shipping Act Lifesaving Equipment Regulations and the I.M.O. Regulations chapter III, Lifesaving Appliances.

The various Lifesaving Equipment regulations currently in force have been designed primarily for ships trading in conditions having little in common with conditions in the Arctic. The regulations do not address the possibility of abandoning ship onto consolidated ice, thin ice or ice conjested waters, situations where the use of a lifeboat may be impossible or, at best, impractical.

Once on the ice, there is currently no satisfactory provision for shelter from the cold, the most important aspect of survival. The use of inflatable rafts is currently advocated for obtaining shelter, yet it is conceded that rafts carried under the regulations are inadequately insulated and may in any case accommodate only 50% of the crew. In one experience (M.V. Cape Freels, March 28, 1976 Eastern Grand Banks) it was shown that survivors were too weak to climb 10 feet up scrambling nets after 12 hours in inflatable rafts and lifeboats. Having been exposed to air temperatures of not less than 0°C, some survivors under these conditions exhibited signs of severe exposure.

By present Canadian regulation:

- Under Section 20 (1)(b)(ii) of the Lifesaving Equipment Regulations, a Class IX ship, other than a tanker, that is a Safety Convention ship, is only obliged to carry one or more liferafts of aggregate capacity to accommodate 50% of the ship's complement.

- Under SCHEDULE XV (5) every Class IX tanker that is a Safety Convention ship or that makes foreign voyages, need only carry liferafts for 50% of the complement.

- Under SCHEDULE V, Section 4, a Class IX tanker not being a Safety Convention ship, that makes home trade 1 voyages, if under 3,000 gross tons is not required to carry any liferafts.

Provisions currently carried in lifeboats and liferafts, although adequate for temperate regions, are considered inadequate in cold regions (Melville, 1984a) where food assumes a greater importance because it is a means of generating body heat.

It is apparent that the primary lifesaving equipment presently required to be carried on Arctic ships is inadequate to preserve life, since;

a) There is no regulatory requirement for lifeboats to be enclosed. Virtually all are open, hence the occupants may be exposed to freezing and dangerous wind chill conditions for long periods before rescue.

b) There are several commonly occurring scenarios where lifeboats or liferafts cannot be safely launched or, if launched, are in danger of upsetting or being crushing by ice.

c) The liferafts tested in accordance with the "Steamship Inspection Standards, 1974" cannot be relied on to inflate within a reasonable period of time when at very low temperatures.

d) The standard immersion suits now provided on-board most Canadian ships are probably unsuitable to ensure survival when the occupant is immersed for long periods in sea water at -1.6°C.

The secondary lifesaving equipment which is presently required to ensure survival once a vessel has been evacuated is unsuitable, since;

a) The Regulations make no provision for insulated clothing to protect survivors against the cold.

b) No means are provided to dry a body when wet, (i.e. heat sources, blankets or dry clothing).

c) In many cases the water rations in the lifeboats will be frozen and no means are provided to melt ice or snow for drinking water.

d) With no means of heating, the lack of warm food will accelerate the loss of heat from the body and may contribute to the lowering of the body core temperature.

e) The rations provided per man do not provide a sufficient daily intake of calories for an extended survival period.

f) There is a lack of shelter if the vessel must be abandoned onto consolidated ice.

g) There is a lack of suitable ice tools to create a shelter from ice blocks, snow, etc. In addition, there is no present training requirement which would instruct survivors on how to build a shelter.

h) There are no means provided to protect against predators.

i) There are no means for the transportation of essential equipment or tools from the vessel across the ice.

j) There is no allowance provided for additional battery power for use with radios, torches and other electrical equipment.

4.2.4 Information Deficiencies

The deficiencies in relation to ship and personnel safety are confined to the requirements placed on the vessel, equipment and personnel in the event of a fire and/or abandonment situation.

a) The unique nature of the Arctic environment requires that special consideration be given to crew survival. The present regulations provide only for ship abandonment in open water with no special consideration given to the Arctic. Research has been performed recently which identifies that shortfalls of the equipment presently carried on baord ship, and which recommends further development and testing of survival equipment and supplies. The recommended programme of research includes:

   - A programme of carefully designed and supervised field tests, of prototype and other available lifeboats and liferafts, to assess their suitability for Arctic use and to validate manufacturers claims.

   - A programme of field tests should be pursued to assess the usefulness and requirements for more apprppriate personnel survival equipment, inlcuding:

- prototype and existing Arctic tents,
- prototype and existing sleeping bags,
- prototype and existing liferafts,
- insulated clothing,
- heatpaks, stoves and lanterns,
- provision pack,
- medical supplies

- A set of field tests, supported by investigations, should be pursued to assess the means of evacuation of personnel and survival equipment onto the ice, and methods of transportation of the equipment away from the ship.

b) Presently there is a lack of formal Arctic survival training. The existing courses on marine emergency duties do not cover the special circumstances which occur in the Arctic, leaving the ships' crew unprepared for the danges of abandoning ship and surviving while waiting for rescue. A training programme should be devised which will properly inform the ships' crews of survival techniques in the variety of conditions in which they will operate.

c) Firefighting systems on Arctic ships must be carefully designed to ensure efficient operation in extreme cold air temperatures. Some systems such as dry chemical powders are not affected by these extremes but the water, foam, and to some extent the gaseous systems, are adversely affected. The effectiveness of each of these systems has yet to be demonstrated during a major fire on board an Arctic ship. Demonstrations should be planned and carried out in extremely cold conditions on board Arctic ships. The results should be documented and used as guidance for operators and for a review of regulatory requirements.

4.3 Navigation

4.3.1 General

Navigation in the Arctic has always presented special problems to ships' officers. The combination of the normal navigation considerations with the difficulties imposed by ice hazard avoidance, the decreased usefulness of electronic navigation aids and the generally poor level of hydrographic coverage serve to make Arctic navigation more challenging.

When reviewing the state of the art of Arctic navigation it is necessary to consider the restrictions imposed by government regulations or guidelines, the available navigation aids, the available shipboard and remote sensors and the present developments in the area of multiple sensor systems.

4.3.2 Government Navigation Publications

4.3.2.1 Regulations

The various regulations within the Canada Shipping Act apply equally to all Canadian vessels whether in Arctic waters or not. Only those directly concerning navigation of vessels in Arctic waters are discussed here.

- Charts and Publications Regulations Part I: this regulation requires that vessels in Canadian Arctic waters shall carry the relevant charts and publications as stated and that they be current and corrected.

- Navigating Appliances and Equipment Regulations: this regulation requires specific equipment to be carried by vessels in certain shipping safety zones.

- The Arctic Waters Pollution Prevention Act deals with construction, navigating equipment, ice navigators, fuel requirements, sewage deposits, oil deposits, Arctic pollution prevention certificates, machinery requirements, zone entry dates, deck watch requirements and radio communications.

The following are also pertinent to Arctic Navigation;

- Arctic Canada Traffic System (NORDREG): a voluntary vessel traffic monitoring and reporting system for the Canadian Arctic.

- Code of Navigation Practices and Procedures: covers principles to be observed in keeping a navigational watch and operation guidance for officers in charge of a navigational watch.

- Ice Navigation in Canadian Waters: includes ice advisory and shipping support services, navigation in ice and regional ice conditions in Canadian waters. This is now under revision.

- The Mariners Handbook: contains information of general interest to mariners including Navigational information, Glossary of terms, Use of charts and Publications, Traffic Regulations, Distress and Rescue, General Oceanography, Meteorology, Ice, Arctic Survival and various tables.

The Collision Regulations are not discussed here as they make no specific reference to Arctic waters, although they must be strictly adhered to at all times and are implied throughout.

4.3.2.2 Hydrographic Charts

The Canadian Hydrographic Service (CHS) currently produces approximately 200 charts of the Canadian Arctic, their scales varying from 1:500 to 1:5,000,000, with most navigable areas covered at 1:500,000.

Very little of Canada's Arctic waters has been surveyed to modern standards (Sailing Directions, Arctic Canada: Volume 1). Except for Lancaster Sound, Barrow Strait, the Beaufort Sea, Amundsen Gulf and the approaches to settlements and some mining sites, spot soundings taken through the ice or reconnaissance track soundings are the only survey data available in the Arctic. In the case of the Beaufort Sea, it will be necessary to re-survey a major portion due to the existence of a large number of submarine pingos. In the areas covered by spot soundings, the density is variable and, in most cases, shoal examinations have not been undertaken.

Survey work is constantly being undertaken, however the area is so vast that many years of work are required before the Arctic is surveyed to the standards found on the eastern seaboard of Canada. While much useful work has been completed, a great deal still remains to be done before satisfying regulatory authorities, underwriters, the owners and, last but not least, the Masters and mates who will be sailing those waters.

4.3.2.3 Tide and Current Tables

The Canadian Tide and Current Tables, Volume 4, cover the Canadian Arctic and Hudson Bay Figure 4.3.1. Unfortunately the volume contains no current tables.

As with charts, tide and current data are being assimulated on an ongoing basis. However, except in a few localities, tide and current data are very limited, being based largely on casual and discontinuous observations, sometimes of doubtful accuracy. This lack of information, especially current information, can and does cause problems when docking. At Little Cornwallis Island, for example, the current appears to be running north to south, however it has been noticed that there is a strong opposing current occurring at random intervals.

A regional study of near surface currents in western Baffin Bay was carried out in 1980 by Arctic Sciences Ltd. (Fissel, 1980) as part of EAMES and this appears to be the most recent study of currents in the Eastern Arctic. There is a need for more local studies, especially in the vicinity of the various wharves and landing beaches.

4.3.2.4 Sailing Directions

The Canadian Arctic is covered by three volumes of Sailing Directions. Volume I consists of general information pertinent to the whole Canadian Arctic. Volumes II and III give detailed descriptions and directions for the Eastern and Western Arctic respectively. The detail of information regarding coastlines, local ice conditions, shoals, etc. is poor compared to the Sailing Directions of, for example, Nova Scotia.

4.3.3 Navigation Aids

The Arctic is poorly served at the present time with navigational aids, and accurate position fixing is difficult. Considering radio fixing aids:

- LORAN C provides no Arctic coverage except in the eastern approaches to Lancaster Sound, where accuracy is suspect.

- DECCA provides no coverage north of 65°N latitude.

- OMEGA is available across the Arctic but extreme caution must be exercised in its use, particularly in the eastern Arctic where its signals are weak due to a loss of signal from Norway caused by the shadow of Greenland. Accurate position fixes can, however, be obtained in the Beaufort Sea area.

  Both LORAN C and OMEGA are subject to errors due to high latitude ionospheric disturbances which introduce errors into the published sky wave correction tables. Errors in sky wave corrections can be expected to change hour by hour and are likely to be greatest when dawn or dusk occurs on the path between receiver and transmitter being used.

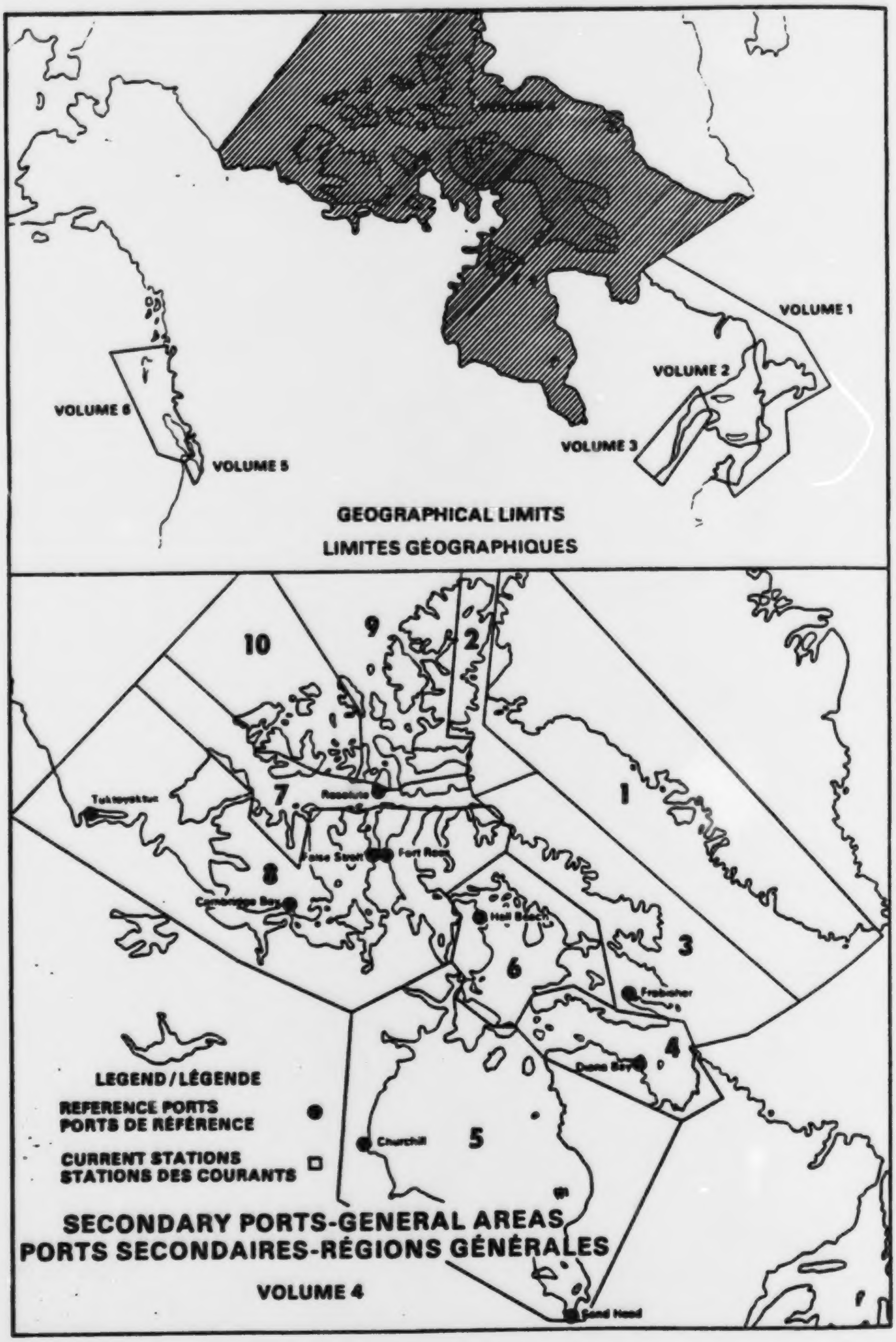
- TRANSIT is a five satellite system through which accurate position fixing (+1 - 1/2 nm.) can be obtained from signals transmitted from a satellite orbiting 1,000 km above the earth. The time interval between fixes may lie between 20 and 40 minutes depending on the latitude of the ship. Between fixes, positioning is carried out by dead reckoning, which is subject to error, depending on the accuracy of the ship's log and compass, compounded by ice conditions and their influence on vessel routing.

- The GLOBAL POSITIONING SYSTEM (GPS) is a new satellite-based radio navigation system being developed by the United States Department of Defence. This system provides two coded signals, P code (military) and C/A code (commercial). Twenty-one satellites will be positioned (18 operational, 3 spare), orbiting above the earth at a height of 20,000 km and position fixing of the accuracy of about 50 meters (or less) will be obtainable 24 hours a day in any part of the world, since at least 4 of the satellites will be visible anywhere. Five prototype satellites are currently orbiting, and replacement by production models is scheduled to commence in 1987. By 1990 the complete 21 satellite system will be in place, subject to the availability of launch systems.

- RADIO BEACONS are located throughout the Canadian Arctic. The accuracy of such beacons in general is suspect and consequently little reliance can be placed on them. They are still, however, used as a backup system and by vessels not having the TRANSIT or G.P.S. systems.

FIGURE 4.3.1

CANADIAN TIDE AND CURRENT TABLES VOLUME 4 COVERAGE AREA


VOLUME 4
VOLUME 1
VOLUME 2
VOLUME 3
VOLUME 6
VOLUME 5
GEOGRAPHICAL LIMITS
LIMITES GÉOGRAPHIQUES
10
9
2
1
7
8
6
3
4
5
Tuktoyaktuk
Resolute
Fort Ross
Cambridge Bay
Hall Beach
Frobisher
Churchill
LEGEND / LÉGENDE
REFERENCE PORTS PORTS DE RÉFÉRENCE ●
CURRENT STATIONS STATIONS DES COURANTS ☐
SECONDARY PORTS-GENERAL AREAS
PORTS SECONDAIRES-RÉGIONS GÉNÉRALES
VOLUME 4

By far the most important development in the field of "Navaids" is the G.P.S. and, once fully operational, it will be of great value to Arctic shipping. The system is shown diagrammatically in Figure 4.3.2.

4.3.4 Shipboard Sensors

Traditionally, hazard detection in Arctic waters has been carried out visually. From the 1950's until very recently, although ships had some assistance from radar, it was still the accepted practice to stop and wait for good visibility. Now that ships are expected to operate continuously, around the clock, and may eventually operate throughout the winter in darkness, this practice is no longer practical. Consequently various devices have been and are being developed.

4.3.4.1 Searchlights

Although searchlights have been in use for some time it is only recently that significant development has impacted on Arctic vessels.

In 1980 MPB Technologies Inc. began development of a 50 kw Vortex collimated, plasma arc, high intensity light source for marine use (TAM 1980). Unfortunately, continued research into this device appears to have ceased. In 1982 commercially available 1000 Watt Xenon arc searchlights were evaluated on-board the ARCTIC. Although, these searchlights have greatly aided the detection of ice hazards, problems have been noted in the ability to distinguish between ice types, due to shadows and colour distortion. Currently a 2.5 K.W. Xenon arc is available on the market but no known ship evaluation has been made.

In conjunction with the test mentioned above, an evaluation of image intensifiers was carried out, but the results were disappointing. It was found that the searchlights produced too much light for the image intensifiers to be used and the range was too short for them to be used on their own. Colour filters have also been tried in conjunction with the searchlights but not directly on them.

4.3.4.2 Radar

Although radar has been in general use on-board ships since the 1950's, it was not until the 1980's that serious research was started to develop an improved marine radar as an ice hazard detector. This came about as a result of various projects, notably the Arctic Pilot Project (APP), Beaufort Sea drilling, Labrador Shelf drilling and coincident with the operation of the ARCTIC.

The conventional marine radar consists of three main components: the scanner, the transceiver and the display. For the most part, marine radar systems have been designed to provide the optimum target detection in sea clutter and foul weather. Until recently, little or no effort was put into modifying the average radar for imaging ice.

FIGURE 4.3.2

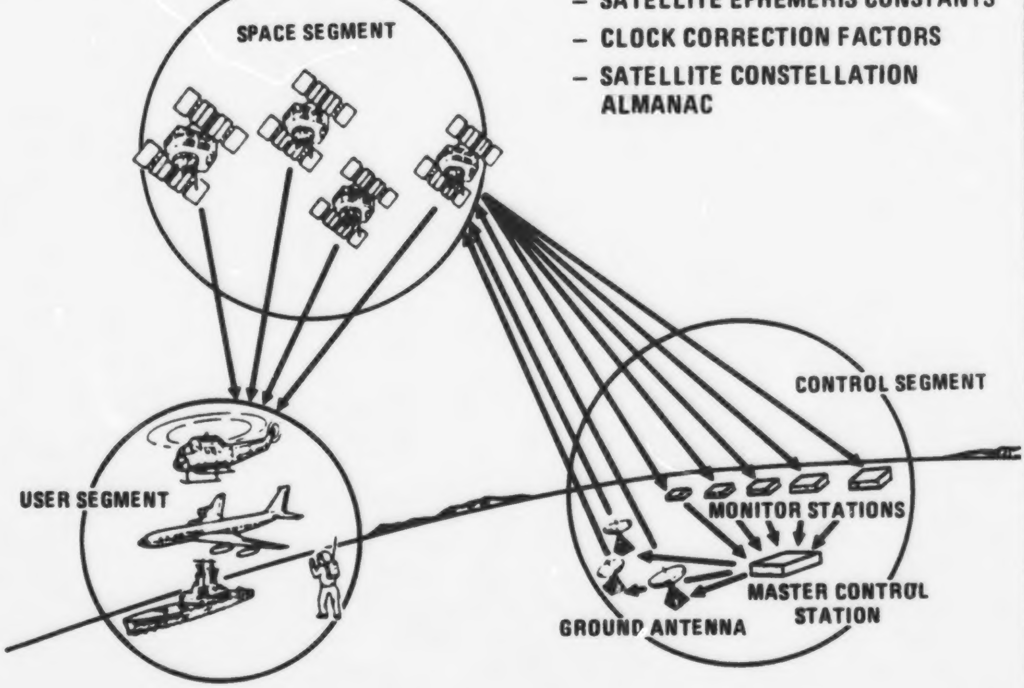
THE GLOBAL POSITIONING SYSTEM
(G.P.S.)

SATELLITE TO USER BROADCAST DATA

- C/A & P CODE RANGING SIGNALS
- SATELLITE EPHEMERIS
- CLOCK CORRECTION
- SATELLITE CONSTELLATION ALMANAC
- TWO-FREQUENCY DATA FOR ATMOSPHERIC CORRECTIONS

SATELLITE TO CONTROL UPLINK DATA

- SATELLITE EPHEMERIS CONSTANTS
- CLOCK CORRECTION FACTORS
- SATELLITE CONSTELLATION ALMANAC


SPACE SEGMENT
CONTROL SEGMENT
USER SEGMENT
MONITOR STATIONS
MASTER CONTROL STATION
GROUND ANTENNA

The antennae on standard marine radars are generally some 2 to 3 metres long for X-band and perhaps as long as 4 metres for S-band. Recent studies have shown that S-band radars may produce images which show returns ore clearly from physically significant targets. S-band, however, is poorer at detecting low-lying targets than X-band. Haykin et al (1985), have concluded that some improvement in imaging ice can be achieved by employing two radars operating at widely separate frequencies. They have also shown that, under some conditions, cross-polarized radars may be very useful for hazard detection (e.g., icebergs). It is not clear, however, if the operational users for such radars will justify their higher costs (Intera, 1985).

Various experience with radars mounted on drilling systems has shown that the antenna should be installed as high as possible to improve long range target detection and ice imaging. The radar resolution should also be as fine as possible to reduce clutter. This can be achieved by installing a larger antenna with very narrow beam width. Increasing antenna size also increases gain, resulting in improved detectability at long range (Ryan, 1985).

The transmitter used in most standard marine radars is a magnetron with typical power of 3-100 kw. Coherent radars, which have been very effective in air traffic control and military surveillance, are also being experimented with. This allows signal processing to be applied, which may distinguish radar returns from moving targets like sea clutter. The major drawback of these systems is reported to be their significant increase in cost.

A typical marine radar (3 m antenna, 25 kw transmitter, low noise amplifier) mounted 30 m above sea-level can detect 'rough' floes at 6-7 nm. The standard display is the Plan Position Indicator (PPI), where the video is displayed on a cathode ray tube with a carefully selected phosphor. Basically, returns are classified as target or noise by the electronics (under operator control) and targets are "painted" bright while noise which is painted black is not seen. In a complex ice field all the ice is painted bright and may saturate the display. This makes it difficult to get adequate definition of shapes and ice types.

Advanced radar aids (ARPAS) are radar systems designed to automatically track individual targets. These systems work extremely well for point targets like other ships and icebergs. They have not been designed to keep track of distributed targets like ice floes. However, theoretical studies have been carried out to assess the feasability of tracking icebergs with radar using target enhancement systems (Ryan, 1986).

4.3.4.3 Sonar

Sonars consist of a transducer or transducer array which transmit a short burst of acoustic energy and then listen for an echo, the time between transmitted and received signal determining the range of the target. The operating frequency of sonar may be from a few KHZ up to 500 KHZ (Benedict, 1979).

One of the major parameters in the choice of operating frequency is transmission loss in the medium which increases as frequency increases. This means that in order to increase useable range, the operating frequency should be as low as possible. However, the extent to which frequency can be lowered is limited for two reasons:

- as the frequency decreases the transducer size must increase in order to keep angular resolution small,
- lower frequency requires longer burst lengths which means poorer range resolution.

An evaluation (de Heering, 1986) of a commercial fish-finding sonar in an iceberg detecting role was undertaken during July and August, 1984, in the Davis Strait/Baffin Bay region of the Canadian Arctic. A C-TECH CDS-40A sonar with an operating frequency of 36 KHZ was mounted within the hull of the ARCTIC and lowered as required. The sonar was used in a programme of sea trials during a 72 hour period on a voyage between Antwerp, Belgium, and Nanisivik in Baffin Island.

The results suggest that a commercially available calibrated sonar system can be used to obtain quantitative and qualitative data which relate echo level (amplitude) to iceberg size. Measurements of echo level from ice pieces less than 100 tonnes and very large icebergs greater than 10 million tonnes indicate a range in values of target strength from -15 db to 35 db per square metre. Also, variations up to 40 db in target strength were obtained from multiple measurements on particular icebergs (de Heering, 1986).

Compact, high frequency (100-300 KHZ) sonar sensors used for underwater surveying have good resolution (1^{o} angular, 0.1 m range) but useable range is limited to about 200 meters. Military ASW (Anti-Submarine Warefare) Sonar which operate in the 10 KHZ range have useable surface ranges of from 0.5 to 3 nautical miles but poorer resolution (about 20 meters and 10^{o}).

4.3.4.4 Low Light Television

In the late 1950's, the term "low light level television" meant a system which could work well outdoors in natural lighting on a December afternoon. Today, low light TV systems are available which are rated to operate in starlight conditions (Benedict, 1979).

The two types of low light television cameras in use today are the vidicon, or intensified vidicon, and the image isocon. Although the image isocon is more sensitive than the vidicon, the latter is preferred because of its more attractive size and cost. The TV tube's sensitivity can be improved by adding an image intensifier, an active vaccuum sealed electron tube which converts the optical image into an electric signal, amplifies the signal and then projects this amplified signal onto a phosphorus screen.

Camera systems are available which give high resolution pictures even under starlight conditions. Whether or not they give sufficient resolution and range for iceberg detection is not known and would need field evaluation.

4.3.4.5 SODAR

SODAR is an in-air acoustic detection technique which is still in the concept stage. It is thought that the device may help to detect icebergs and ice fragments at short range.

4.3.4.6 CODAR (HF)

CODAR (HF) is a high frequency over-the-horizon radar system. The application of this system is to detect and track icebergs in order that a greater level of accuracy may be obtained by drilling operations in determining whether or not the icebergs pose a collision threat.

4.3.5 Remotely Sensed Information Sources

4.3.5.1 SLAR

Real aperture side looking airborne radars (SLARs) have traditionally been used to provide wide area photo-like imagery (50-100 km per side) shown on Figure 4.3.3, of Arctic sea ice. Ice classification is made on the basis of tone, texture and context of the data.

The most severe drawback of SLAR for ice reconnaissance is that their azimuthal resolution varies as a function of range (typically from 50 m at near range to 500 m at far range). Furthermore, it becomes very difficult at far ranges to distinguish in-ice features essential for classification. Real aperture SLAR does provide a good overview for applications which don't require better resolution. For example, it is adequate for strategic route planning but is not suitable for tactical support (Canarctic, 1985).

4.3.5.2 SAR

The Synthetic Aperture Radar (SAR) discussed here is also used in a SLAR configuration. However, it provides a much improved resolution compared to the real aperture SLAR. The SAR achieves a very fine resolution in both range and azimuth by the use of signal processing. An encoded transmit pulse is used to generate a return pulse that can be compressed to any resolution. Improved azimuth resolution is achieved by compressing the entire doppler spectrum returned from a range cell as the radar passes over. By calculating the exact compression required at each range, azimuth resolution becomes independent of range.

Provided sufficient power is available, the aircraft platform can fly as high and look out as far as practical and still achieve the same ground resolution. SAR can thus provide an accurate map of ice conditions in sufficient detail to steer a ship, as shown on Figure 4.3.4.

FIGURE 4.3.3

A.E.S. - NDZ SLAR
Image scale 1:250,000

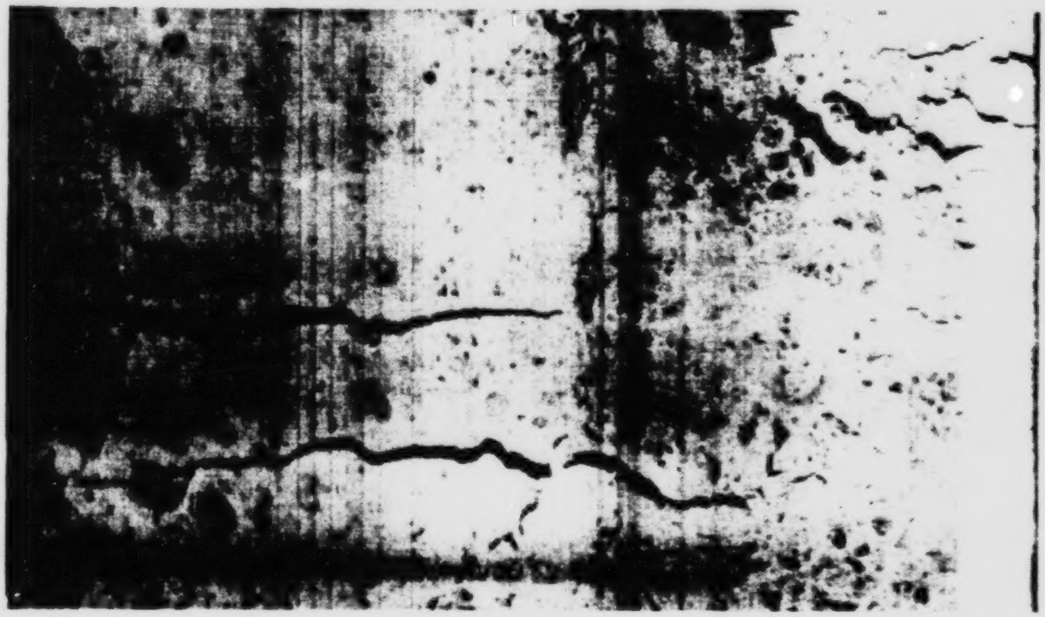
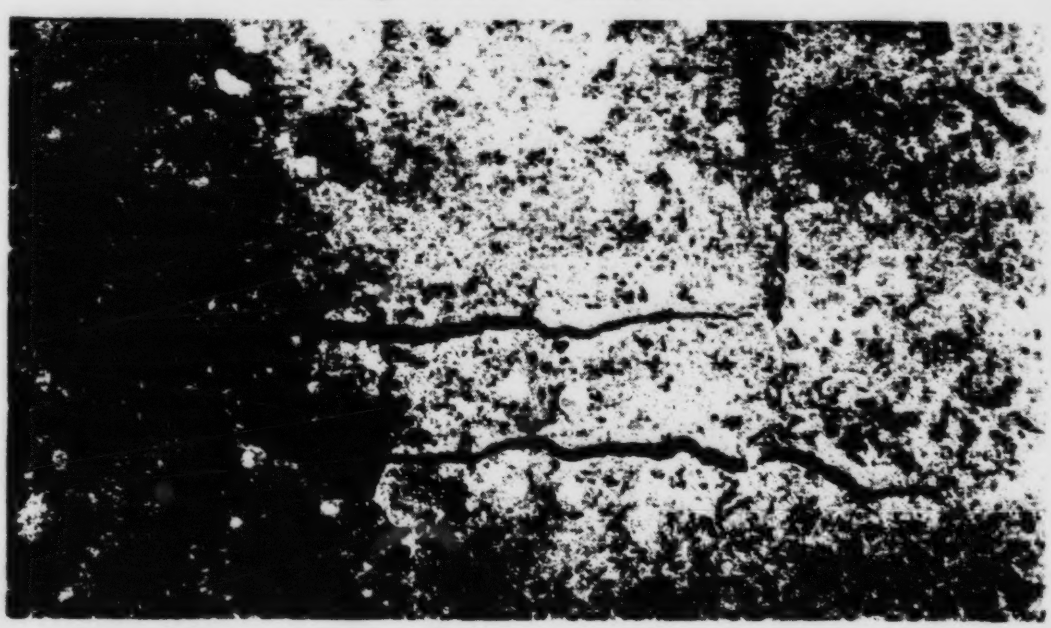


FIGURE 4.3.4

INTERA STAR - 1 SAR
Image scale 1:250,000



The only commercial SAR flown in Canada is operated by Intera Technologies Ltd. Intera's STAR-1 is an all-digital, high resolution SAR that typically images a ground swath of 50 km, resolving ground pixels of 12 metres by 12 metres. This data, after downlinking to a ship, is degraded to a resolution of about 24 m (Canarctic, 1985).

A narrow swath (25 km) higher resolution mode is also available, with a ground resolution of 6 metres. STAR-1 is a '7-look' radar. This means that 'coherent speckle', which is a noiselike artifact of all SAR systems, is effectively suppressed (Intera, 1985a). Together with the resolution achieved, this provides crisp, easily interpreted imagery from which the features of interest (multi-year floes, ridges, leads, etc.) can be identified.

The radar is flown in a small twin-engine turbo-prop aircraft (Cessna Conquest) at a typical operating altitude of 10 km. This provides a range of depression angles across the 50 km swath from 30° to 9°. These are near optimum for extraction of sea-ice information (Intera, 1985a). The endurance of the aircraft allows large areas such as Baffin Bay or Lancaster Sound to be mapped during a single mission.

Due to the relatively high resolution and the ability to downlink to ships having the required receiving capability, this system has been very successful operationally. The detail has been such that tactical routing of vessels by this means has not only saved time but has enabled those vessels to avoid all but the smaller (50 m) multi-year floes.

4.3.5.3 Satellite Imagery

The passive sensors are basically receptors of the spectral emissions of surfaces. The spectral information can range from the visual, through the infra-red (IR), to the microwave. Their function is based on the fact that spectral characteristics are related to various physical properties of the surface or material.

Several satellites such as the NOAA, DMSP, and the NIMBUS series also carry thermal infrared (IR) sensors. The most important advantage of the IR sensors is their ability to operate in darkness and bad weather. Their limited resolution only permits the identification of gross ice boundaries and overall features within the ice pack. Ship-mounted IR systems for ice detection have received little attention.

Experiments involving the direct reception of satellite imagery have been carried out by Canarctic using a Muirhead VIEWFAX system. These experiments have demonstrated that the visual band is more useful in ice detection than the IR band of the NOAA satellite images (Canarctic, 1985) during periods of daylight. The imagery received can be manipulated by a number of operator defined transforms to enhance the image display. This system has proved to be a useful tool in strategic planning. No assessment has been made of IR imagery during darkness, however it is anticipated that this will be carried out in the near future.

Passive microwave radiometers can be both satellite mounted and airborne. Several satellites from the NIMBUS series and also the Seasat carry these radiometers. Between the years 1970 and 1972 the NASA Arctic Ice Dynamics Joint Experiment (AIDJEX) demonstrated the usefulness of airborne microwave radiometers in distinguishing between old and new ice and the tracking of ice motion.

4.3.6 Multiple Sensor Systems

Because no one sensor has been found to operate well under all conditions or for all ice types, attention has been directed towards the development of multiple sensor systems (Canarctic, 1985, 1986). In general terms these systems are attempting to integrate information from diverse sources and topresent this information in a form easily interpreted by the navigator.

Canarctic Shipping Company Limited have been working towards the development of an integrated ice information system known as "SINSS" (Shipboard Ice Navigation Support System). This system, diagrammatically shown in Figure 4.3.5, has demonstrated that real-time ice information which is available from sources like airborne radars (SAR, SLAR), marine radars, and satellites (IR/visual), can be used for better route planning and tactical navigation by ships in transit through ice (Canarctic, 1986). With knowledge of the ice conditions in an operational region, a ship's Master can optimize his route and avoid areas where the risk of contact with ice or heavy ice is great. The resulting savings in ship operating costs, reduction in vessel damage claims, and improvement in delivery schedules have proven to be very substantial.

One of the key concepts to emerge from this research is that of an "ice navigation chart". Typically, navigators have charts of the worlds oceans; however, what is required for operations in the Arctic is a similar chart showing detailed ice conditions. This requires information superior to that which has been available in the past. Features such as old ice and icebergs, with sizes of the order of tens of metres, should be shown on the chart. Areas of ice rubble, ice build up and ice compression also need to be shown. Because ice conditions change rapidly this information must also be available in real-time.

Airborne radar SAR imagery like that available from Intera's STAR-1 provides the right image characteristics and the right level of information to be used as an ice navigation chart. By staging periodic airborne radar missions, geographically annotated airborne radar data can be telemetered to the bridge of a ship in real-time and used for ice navigation. The marine radar provides the means of tracking the position of the ship on the SAR imagery when ice conditions have changed. The geometric structure of SINSS is shown in Figure 4.3.6.

SINSS is a multi phased programme conceived in 1983 when Canarctic Shipping Company Limited began a conscious effort to extend the ARCTIC's trading season in the high Arctic. Phase 1 considered the development of a conceptual design and initial field trials were undertaken in 1983. Phase

FIGURE 4.3.5

SHIPBOARD ICE NAVIGATION SUPPORT SYSTEM
(SINSS)

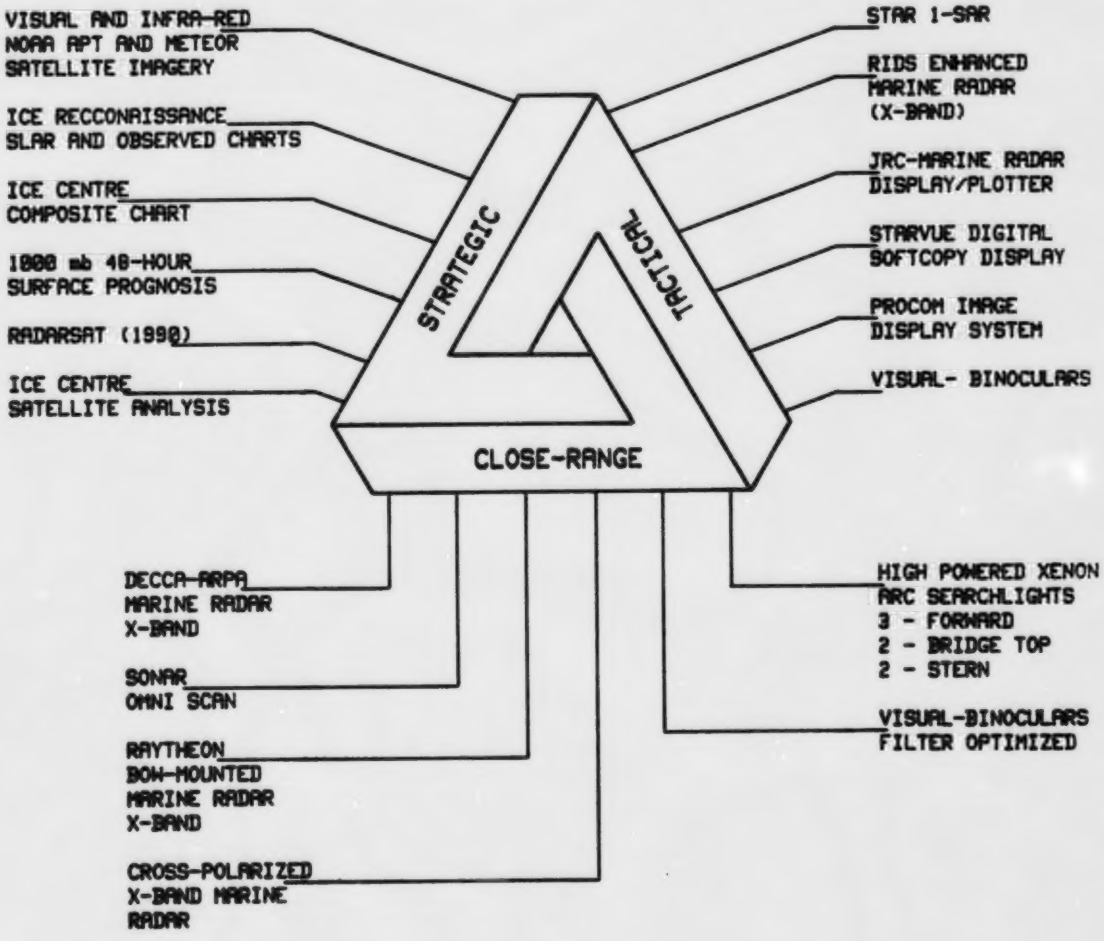

VISUAL AND INFRA-RED NOAA APT AND METEOR SATELLITE IMAGERY
ICE RECCONAISSANCE SLAR AND OBSERVED CHARTS
ICE CENTRE COMPOSITE CHART
1000 mb 48-HOUR SURFACE PROGNOSIS
RADARSAT (1990)
ICE CENTRE SATELLITE ANALYSIS
STRATEGIC
TACTICAL
CLOSE-RANGE
STAR 1-SAR
RIDS ENHANCED MARINE RADAR (X-BAND)
JRC-MARINE RADAR DISPLAY/PLOTTER
STARVUE DIGITAL SOFTCOPY DISPLAY
PROCOM IMAGE DISPLAY SYSTEM
VISUAL- BINOCULARS
DECCA-ARPA MARINE RADAR X-BAND
SONAR OMNI SCAN
RAYTHEON BOW-MOUNTED MARINE RADAR X-BAND
CROSS-POLARIZED X-BAND MARINE RADAR
HIGH POWERED XENON ARC SEARCHLIGHTS
3 - FORWARD
2 - BRIDGE TOP
2 - STERN
VISUAL-BINOCULARS FILTER OPTIMIZED

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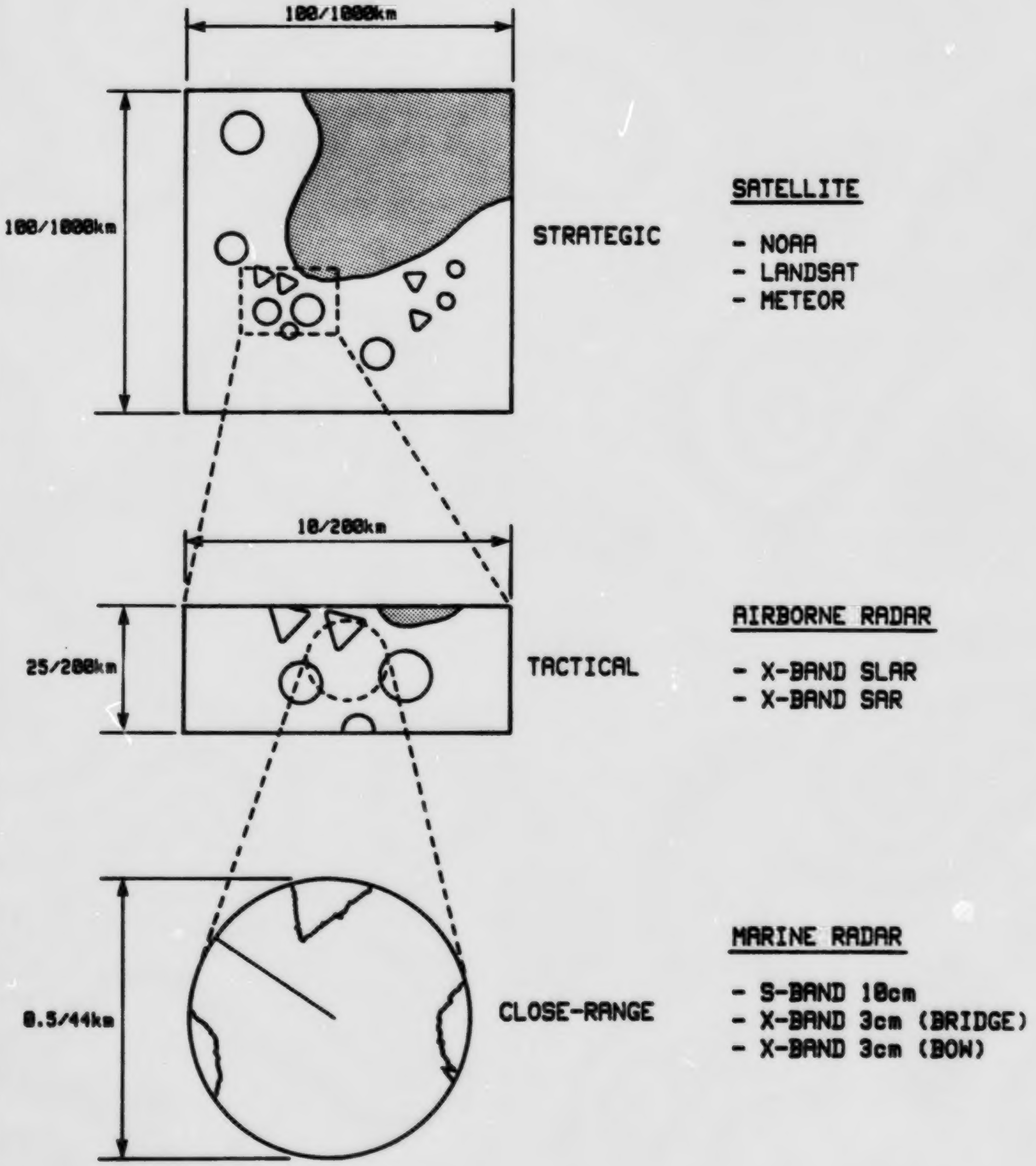
FIGURE 4.3.6

THE GEOMETRIC STRUCTURE OF A SHIPBOARD ICE NAVIGATION SUPPORT SYSTEM (SINSS)


100/1000km
100/1000km
STRATEGIC
SATELLITE
- NOAA
- LANDSAT
- METEOR
10/200km
25/200km
TACTICAL
AIRBORNE RADAR
- X-BAND SLAR
- X-BAND SAR
0.5/44km
CLOSE-RANGE
MARINE RADAR
- S-BAND 10cm
- X-BAND 3cm (BRIDGE)
- X-BAND 3cm (BOW)

II, undertaken during the 1984 shipping season, defined the minimum acceptable standard of information required. Phase III, undertaken in 1985, concentrated on hardware design and system testing.

4.3.7 Precise Navigation Systems

This aspect of navigation, which is in use in various ports around the world, has only very recently been applied to Arctic harbours.

In its simplified form a PINS is the navigational task accomplished electronically. The ship's position is obtained and automatically plotted on a VDU. The system can then be broken down into "positioning systems" and an "electronic chart system". Between the two is an integrated navigation system to combine positioning information and weigh it according to reliability. The "integrated navigation system" may either be part of the navigation system or the electronic chart system.

The three systems which seem to offer the best chance of availability and which are described in this section are:

- A microwave transponder precise inshore navigation system by Offshore Systems Ltd. of Vancouver.

- A passive radar reflector ranging system being researched by McMaster University.

- Future satellite navigation systems.

a) Precise Inshore Navigation System,
9,000 Series (PINS 9000)

The PINS 9000 is an integrated navigation system which is capable of analysing information from a variety of sources and displaying a scaled ship shape on the Visual Disply Unit (V.D.U.). This gives the master the position of his vessels bow and stern with relation to charted hazards and tracks the movement of the vessel with an accuracy in the area of +/- 2 M. This system was tested during the ARCTIC's docking at Rea Point 1985 and, although the system aided docking manoeuvres there, it was unreliabile and was eventually shut off. No further testing of this system has been carried out on the ARCTIC.

b) Precise Radar Navigation System (PRANS)

The PRANS proposal for ranging with the ship's radar on specially designed radar reflectors installed in known shore location is just one of the many electronic fixing systems which may be used for feeding information to a ship's integrated navigation computer. The unique advantage of the PRANS system for Arctic navigation is its shipboard self sufficiency as it ranges on the radar transmission returning from passive reflectors ashore which require no power source.

The system is based on an ordinary "X" band marine radar to measure the distance of two or more passive radar reflectors. A mini-computer is programmed to use these distances in conjunction with the known location of the transponders to calculate the vessel's position with reference to a predetermined course line. Vessel movement along the channel is automatically switched from one set of reflectors to another. Information obtainable from the system includes cross track error, distance to next turning point, position in the channel, attitude in the channel and speed. This system has been tested successfully in the St. Lawrence River, although it is not known whether the system has been used in the Arctic.

c) Future Satellite Navigation Systems

The existing U.S. Navy Transit SATNAV is quite accurate and reliable for offshore navigation in the Canadian Arctic but the accuracy level is too low for the precise fixes required when navigating through shoals, narrow channels and port areas. This system is being phased out as the new NAVSTAR Global Positioning System (GPS) gives increasingly improved coverage.

G.P.S. in the differential mode eliminates the errors inherent in the system by making position measurements at a known point. The error is computed by a static receiver which transmits the errors to users in the vicinity. It is claimed the system will have a ± 5 m accuracy within 200-500 km of the monitoring station. The system is shown diagrammatically in Figure 4.3.7.

4.3.8 Information Deficiencies

The deficiencies in relation to ship navigation relate mainly to lack of ability to detect ice and to understand the nature of the ice cover ahead of the ship. Successful navigation through areas of severe ice cover has been demonstrated with the aid of remotely sensing systems. However, this work is very much in the development stage and must be completed to secure the full benefits.

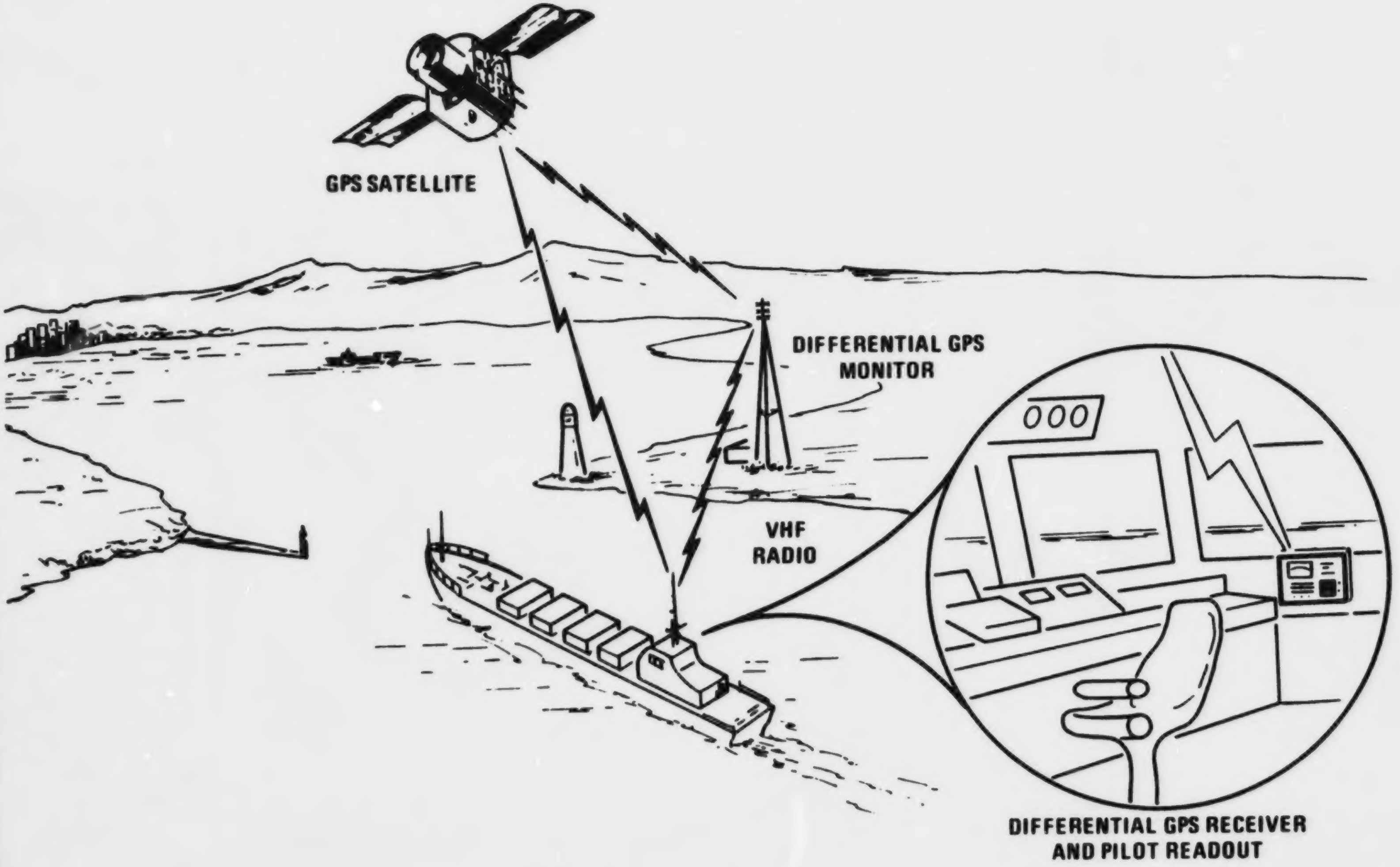
a) SINSS has proven to be a most valuable tool, however, the system requires operational assessment and fine tuning under winter conditions. The areas requiring improvement are:

   - utility of the METEOR APT Satellite images.
   - utility of ice forecasting services.
   - improved weather data acquisition.
   - improved soft copy downlink systems.
   - improved high speed computer manipulated and enhanced marine radar displays.

b) It is unlikely that electronic sensors will ever fully replace the visual detection of hazardous ice, in the close tactical sense. Therefore, it is most important that continued research be carried out to improve searchlights or other light sources. The present difficulty in distinguishing between ice types when using searchlights should be examined and solutions sought.

FIGURE 4.3.7

DIFFERENTIAL GLOBAL POSITION SYSTEM


GPS SATELLITE
DIFFERENTIAL GPS MONITOR
VHF RADIO
000
DIFFERENTIAL GPS RECEIVER AND PILOT READOUT

MELVILLE SHIPPING LTD

c) In order to improve marine radar detection techniques a data collection programme is necessary to obtain radar data for small ice targets in sea clutter. In addition, investigations should be continued into data processing techniques which show promise for increasing signal-to-noise ratio and signal to clutter rations.

d) Field programmes are necessary in order to support and extend present knowledge regarding fundamental properties of acoustic propagations in Arctic waters. Important here are investigations into the frequency dependence of target strength and in the signal to noise aspects of various transducer configurations and installations. Propagation characteristics under ice also demands attention. From a theoretical point of view some research into the statistical nature of sonar echoes and their relationship with radar echoes from the same target is also thought to be important.

Of more immediate concern to the design of a suitable sonar for ice hazard detection are the hardware problems associated with the deployment of a transducer assembly within the bow area of the vessel. In this respect the positioning and 'look direction' of a sonar transducer would have to be identified and the beam pattern and scanning rates defined. Further investigation into ship and ice generated noise is also desireable.

e) A programme should be pursued of continued Arctic class Nav-Aids research, development and implementations having due regard to the eventual impact of GPS on the need for traditional Nav-Aids. Emphasis should be on the Coronation Gulf route through the North West Passage.

4.4 Communications

4.4.1 General

Ships all over the world depend upon an effective maritime mobile communications service for the safe and efficient management of their voyages. This observation is never more applicable than in the Arctic because of its hostile climate, uncharted waters and vast expanses in which there are few ships that can help in case of emergency.

Canada, as a signatory to the SOLAS Convention, has an obligation to provide those maritime mobile communications facilities deemed practicable and necessary for the safe passage of shipping in Canadian waters.

Under the provisions of this Convention, nations agree to enforce minimum standards of safety, including the provision and operation of adequate communications equipment, for ships sailing under their flags on international voyages.

Radio requirements for Canadian ships are contained in the "Ship Station Radio Regulations" and "Ship Station Technical Regulations" of the Canada Shipping Act.

Radio communications beyond "line of sight" limits in the Arctic create certain problems that occur only rarely in lower latitudes.

Ionospheric disturbances are the main factors which effect the behaviour of radio waves in the low frequency (LF), medium frequency (MF) and high frequency (HF) bands (Sailing Directins: Arctic Canada-Volume I).

The main ionospheric disturbances are:

- Sudden ionospheric disturbance "flare blackouts".
- Polar cap absorption caused by "solar cosmic rays".
- Ionospheric storms.
- High latitude E and F region variability.

The effects of these so-called magnetic and ionospheric storms, which may persist with varying intensity for several days, are usually greatest in higher latitudes. Radio black-outs and simultaneous deviations of the magnetic compass needle by several degrees are not uncommon in and near the auroral zones. This uncertainty of communications has serious implications for both marine safety and marine operations in the Arctic. Many users of Canada's Coast Guard Radio stations in the Arctic have experienced difficulties due both to atmospheric conditions and to equipment problems.

4.4.2 Coast Guard Radio Stations

Besides meeting the safety requirements of the SOLAS Convention, Canada's maritime mobile communications service must also meet domestic requirements resulting from regulations made pursuant to the Canada Shipping Act and the Arctic Water Pollution Prevention Act, the operational needs of the Coast Guard fleet and, in general, must support waterborne commerce on which so many of Canada's economic activities depend.

To perform these tasks of the maritime mobile communications service, the Telecommunications and Electronics Branch of the Canadian Coast Guard operates and maintains a national network at 52 coast radio stations strategically located to provide optimum coverage according to prevailing ship traffic densities. Of these fifty-two radio stations, seventeen are located in the Arctic.

During their hours of operation, these Radio Stations continuously monitor internationally agreed safety and distress frequencies in the MF and VHF bands, and also selected frequencies in the HF bands. This function enables stations to receive distress, urgency and safety calls from ships thus ensuring the necessary response for such activities as distress detection, search and rescue, medical advice, navigational information, weather reports, position reports, etc. These stations also regularly broadcast, as specified in "Radio Aids to Marine Navigation", the following essential navigational information to shipping by means of radiotelegraphy, radiotelephony and facsimile;

- weather forecasts for specified marine areas,
- actual ice cover conditions and forecast conditions,
- navigational warning messages called "NOTSHIPS" which cover a wide range of conditions from a misplaced position of a buoy to the unavailability of a Coast Guard radio station.

For the shipping company, fast and reliable communications to and from its ships is of the utmost importance for the economic management of its fleet. The "public correspondence service" which the Coast Guard operates makes possible this essential communications link between ships and their shore-located operating base.

This service allows for the sending and receiving of radiotelegrams and where applicable, direct person-to-person contact by radiotelephone. Radiotelegrams and radiotelephone calls are transmitted via the following means:

- Radiotelegraphy: Using Morse code, the ship's radio operator transmits a radiotelegram to the Coast station radio operator, who in turn transmits this radiotelegram via Telex to its destination. The reverse process applies in the shore-to-ship direction.
- Radiotelephony: In this mode, radiotelegrams are radioed by voice communication to a Coast station radio operator, who in turn uses Telex facilities to transmit the message to its destination.
- Marine Telephone Call: If so equipped, a Coast radio station can directly interface a radiotelephone call from a ship into the public switched telephone network. In this manner, direct voice communication between a ship and a location on shore is possible. This service is also referred to as radio patch, duplex calls. It is not private, as other marine stations can listen in without difficulty.

While safety-related messages and those required by the ECAREG or NORDREG systems are handled free of charge, public correspondence traffic is charged for according to approved tariffs.

Until recently, Transport Canada was, for all practical purposes, the only supplier of ship-shore communications in Canada. Today however, Teleglobe Canada has entered the Maritime Mobile Satellite Service through its participation in INMARSAT, and there is the strong possibility that the commercial carriers will participate directly in the Maritime Mobile Service through future VHF/UHF automatic radiotelephone systems.

4.4.3 Forecasts and Ice Advisories

The Arctic Canada Traffic System (NORDREG) Centre at Frobisher Bay opens in early July and is manned until the end of October or as long as ships are at sea in the area. This office provides current information on ice conditions, advice on the best routes to follow, icebreaker support, where available and considered necessary, and the organization of convoys if required.

The daily production of ice forecasts is the responsibility of Ice Forecasting Central in Ottawa. The ice forecasting programme co-ordinates the data recorded during aircraft reconnaissance flights with satellite imagery, shore station observations and ship reports. These and other inputs are used to develop composite charts of current ice conditions. From these charts and predicted meteorological parameters, plain language ice forecasts are prepared and disseminated. In addition radio facsimile broadcasts of these ice charts are made from Coast Guard Radio Stations. The Atmospheric Environment Service (A.E.S.) ice reconnaissance aircraft are equipped to transmit fascimile maps and side looking airborne radar (SLAR) imagery directly to vessels having the receiving equipment. This information is generally real-time or close to real-time.

4.4.4 Radio Communications

Maritime mobile frequency assignments fall into three major categories, commonly referred to as Medium Frequency, MF (300 KHZ-3 MHZ), High Frequency, HF (3 MHZ-30 MHZ) and Very High Frequency, VHF (30 MHZ-300 MHZ). Well known examples of typical maritime frequencies in the MF and VHF frequency bands that have special international status as general calling and distress frequencies are:

500 KHZ/Morse Code (MF)
2182 KHZ/Voice, Radiotelephone (MF)
156.8 MHZ/Voice, Radiotelephone (VHF)

These frequencies may be used by the entire maritime community for the purpose of establishing an initial contact with a coast radio station or another ship or to broadcast an emergency. Therefore, Coast Guard facilities transmitting or receiving on these safety frequencies must have exceptionally high reliabilities.

4.4.4.1 VHF Band (156-174 MHZ)

This frequency band contains the international distress frequency, 156.8 MHZ (Channel 16). Aside from satellites, VHF frequencies guarantee the best quality communication. These frequencies are not affected by atmospheric noise and are free from the vagaries of the ionosphere and the large attenuation experienced by groundwaves. Equipment is reliable and relatively cheap, power requirements are low and installation space and antenna requirements are simple. Their effective range, however, is limited to line of sight distances, which are approximately 40-50 miles depending on the ground elevation and height of antenna installations.

This range limitation is a serious obstacle to widespread use of these frequencies in the vast expanses of the Arctic because, for the same amount of capital investment, substantially larger coverage can be obtained using the other frequency bands.

The VHF band is widely used for ship/ship and port communications.

4.4.4.2 MF Band (405-535 KHZ)

In this frequency band, the use of narrow-band direct printing telegraphy and radiotelegraphy is permitted. Coverage range is good (approximately 300-500 miles) and reliable because propagation is via the groundwave mode and is independent of ionospheric influences. Due to its relatively long-range capability, the MF band is often the only ship-shore communication medium available during a severe blackout condition.

For reasons of safety, therefore, all ships in the Arctic would be well advised to equip themselves voluntarily with this capability, even though current Canadian legislation does not require them to do so.

4.4.4.3 MF/HF Band (1605-4000 KHZ)

The frequency band 1605-4000 KHZ provides for narrow-band direct printing telegraphy, radiotelegraphy and radiotelephony, but current use is limited generally to radiotelephony using 2 MHZ assignments.

This band contains the international distress and calling frequency of 2182 KHZ and, unlike the 500 KHZ/CW frequency, is used by practically all ships plying Canadian waters.

Communication is carried on by voice and, therefore, no trained radio operators are required. Propagation is again, as in the case of 500 KHZ, mainly via the groundwave, but skywave propagation is possible during the night, although this latter mode is unpredictable and quite unreliable. Radio coverage range depends very much on the quality of the particular installation but is generally taken as 150 miles.

4.4.4.4 HF Band (4000-27500 KHZ)

In this frequency band radiotelephony is permitted in the range 4000-23000 KHZ and narrow-band direct-printing telegraphy and radiotelegraphy are allowed from 4000-27500 KHZ. Currently, the most common transmission modes are radiotelegraphy and radiotelephony.

Coverage can be engineered to meet varying operational requirements provided antenna systems are carefully designed to minimize skip distances. The long-range coverage capability of HF is ideally suited for the vast expanses of the Arctic. Since propagation is via the ionosphere there can, however, be conditions when no communications are possible across the entire band (blackout).

4.4.5 HF Modems and Channel Evaluation Techniques

In the past, HF transmission systems have been used primarily to support analog voice communications, and have generally been notoriously unreliable due to the inherently variable nature of the radio channel caused by ionospheric fluctuations, noise and interference. Varying channel conditions necessitate the use of a number of different frequencies over a 24 hour period. Traditionally, HF links have been controlled by experienced radio operators, and the channel selection has been done manually. However, the operator can never have adequate information for efficient control, but must rely heavily on off-line predictions, experience and a subjective assessment of channel quality.

Much more efficient use could be made of the HF medium if the operating frequency could be adaptively adjusted to suit the changing atmospheric conditions. New technology offers several approaches to this concept in the form of automatic real-time channel evaluation and control techniques. Real-time channel evaluation systems make use of a variety of measurable parameters such as:

- signal amplitude/frequency/phase,
- propagation time,
- noise or interference level,
- channel impulse response,
- signal-to-noise or signal-to-interference ratio,
- energy distribution within the channel bandwidth,
- received data error rate,
- received speech intelligibility level, and
- rate of repeat requests in an ARQ system.

Commercially available HF transceivers that incorporate real-time channel selection features still use analog transmission techniques. They also offer a low-rate data capability (typically 100-200 b/s) which generally uses FSK modulation. These sort of data rates can be transmitted fairly reliably due to the long bit duration compared to the channel multipath spread (Miller Communications, 1985).

High speed data transmission via HF is now commercially available by the use of 2400 b/s digital modems in conjunction with conventional HF transceivers.

4.4.6 Satellite Communications

4.4.6.1 INMARSAT

The INMARSAT satellite system is somewhat different from those of other organizations which provide a fixed service. INMARSAT interfaces directly to the end user's telephone on the mobile side of the satellite. It extends the terrestrial telecommunications networks to the oceans of the world. When someone on-board a ship picks up the telephone, he is, in effect, using the ultimate in cordless telephones.

The maritime satellite system has three major components: the satellite capacity leased by the organization, the coast Earth stations and the ship Earth station as shown on Figure 4.4.1.

The nerve centre of the system is the operations control centre (O.C.C.) at INMARSAT's head quarters. The O.C.C. is connected directly by its own ship Earth stations to the Atlantic and Indian Ocean satellites, and so to all coast Earth stations around the world. Operating continuously, it coordinates a wide range of activities. Should a serious problem arise with one satellite, putting it out of commission, the O.C.C. would be responsible for taking the necessary steps to transfer traffic to a spare satellite in orbit. The O.C.C. also handles all commissioning applications from ships that have just installed INMARSAT terminals (Lundberg, 1984). The INMARSAT system is now widely used for telephone and telex communications.

The equipment below deck consists of telex and telephone and a variety of optional equipment for facsimile, data and slow-scan television. Low and medium speed data transmission are available via a voice channel at up to 4.8 kbit/s in both directions. With a specially prepared satellite channel in the ship-to-shore direction, high speed data transmission at up to 56 kbit/s is available. INMARSAT has also agreed to make satellite capacity available in the ship-to-shore direction for a very high speed data service (v.h.s.d.), which would allow information to be transmitted at rates of 1 Mbit/s or more.

As can be seen on Figure 4.4.2, INMARSAT does not cover very much of the Canadian Arctic. In practice the coverage area is slightly better than shown, experience has demonstrated for example that contact is possible in the entrance to Lancaster Sound.

4.4.6.2 M.S.A.T.

MSAT is a multi-beam satellite system designed to provide Canada-wide voice and data services to mobile users and planned to be launched in the late 1980's. The system is intended to complement local terrestrial mobile radio networks by taking advantage of the large coverage area afforded by a satellite system (coverage up to roughly 75°N is planned).

The 5 KHZ channels currently planned for MSAT will be arranged in a single channel per carrier format, the majority of which will be allocated on a demand assigned multiple access (DAMA) basis.

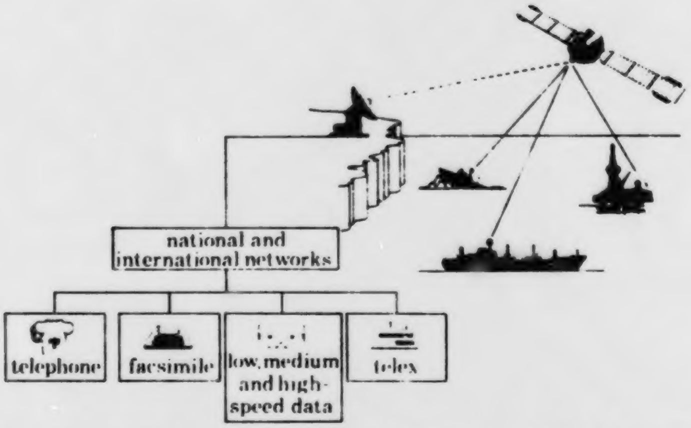
It is anticipated that the 4 MHZ of Bandwidth allocated in the mobile communications band will be divided equally between Canada and the U.S. Current plans for the Canadian MSAT programme indicate that it will either be a 2-beam system with 200 channels (1 MHZ) per beam or a 4-beam system with 133 channels (667 KHZ) per beam (assuming frequency reuse).

4.4.6.3 Telesat Satellite Network

Telesat Canada operates a commercial satellite communications system throughout Canada. The system includes a space segment, consisting of

FIGURE 4.4.1

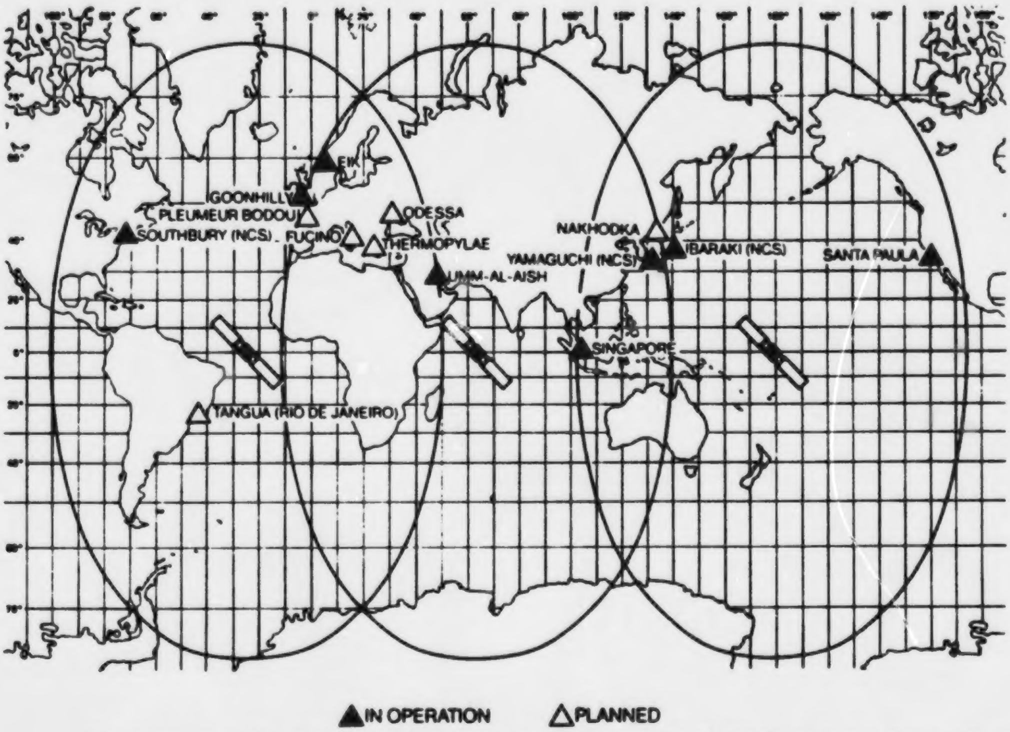
THE INMARSAT SYSTEM


national and
international networks
telephone
facsimile
low, medium
and high-
speed data
telex

The Inmarsat system comprises three main elements: the satellites, the coast Earth stations and the ship Earth stations. The coast Earth station provides the link with the national and international telecommunications networks. The broken line represents transmissions to the satellite at 6 GHz and reception from the satellite at 4 GHz; the solid lines represent transmissions at 1.6 GHz and reception at 1.5 GHz.

FIGURE 4.4.2

EXTENT OF THE INMARSAT SYSTEM


EIK
GOONHILLY
PLEUMEUR BODOU
SOUTHBURY (NCS)
FUCINO
ODESSA
THERMOPYLAE
UMM-AL-AISH
NAKHODKA
YAMAGUCHI (NCS)
IBARAKI (NCS)
SANTA PAULA
SINGAPORE
TANGUA (RIO DE JANEIRO)
▲IN OPERATION
△PLANNED

The Inmarsat satellites provide near global coverage (to about the 75° latitudes) so that a ship can communicate via satellite virtually anywhere. As of 1 December 1983, there were eight coast Earth stations in operation with several more scheduled to joint them in 1984. Three of these are Network Coordination Stations (N.C.S.), which assign telephone channels on demand to requesting ship Earth stations.

active 6/4 GHZ and 14/12 GHZ satellites in geostationary orbits, and over one hundred earth stations of several different types. Currently, both the remaining Anik A Satellites (two of the three launched have already been retired) and the Anik B satellite are nearing the end of their useful lives.

The Anik C series of satellites offer a coverage area that is biased towards southern Canada. The Anik D series operate at 6/4 GHZ and provide all-Canada coverage. Thus far the Anik satellites have not been used by vessels in the Arctic. It appears (Miller Communications, 1985) that the major problems with respect to ship use of Anik D is the stabilization of the large size dish antenna and the associated costs of this installation.

4.4.7 Future Global Maritime Distress and Safety System

F.G.M.D.S.S. will also be a milestone for Inmarsat, because one of its major objectives is to provide improved facilities for distress calls and communications to improve safety of life at sea. The immediacy and reliability of Inmarsat communications have already led some countries to include the ship Earth station as an alternative main transmitter for mandatory carriage on ships covered by I.M.O. Safety of Life at Sea (SOLAS) Convention. Many more countries are expected to follow suit as I.M.O. prepares its new SOLAS requirements and its proposals for the F.G.M.D.S.S. According to I.M.O., the F.G.M.D.S.S. is intended to be a comprehensive system, Figure 4.4.3, to improve distress and safety communications and procedures which, in conjunction with a coordinated search and rescue infrastructure, will incorporate recent technical developments.

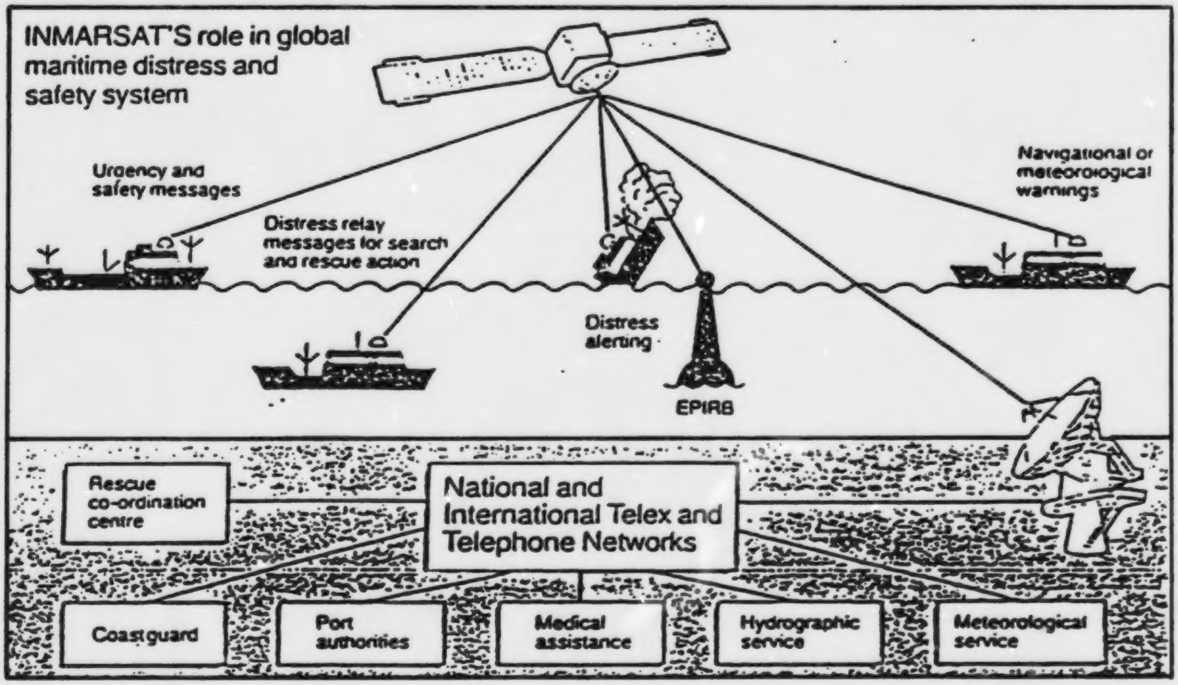
One objective of the future system is to enable any properly equipped ship to achieve automatic distress alerting and be located with minimum delay. As well, it is expected that most rescue centres will be equipped with satellite communications so that they can have direct access to the Inmarsat system and will, as a consequence, be able to contact vessels similarly equipped in seconds in the event of a distress or emergency at sea.

Inmarsat is expected to play a major role in the F.G.M.D.S.S. I.M.O. has said the F.G.M.D.S.S. will use both satellite and terrestrial communications. Satellite communications will be provided by Inmarsat. A distress capability for alerting by satellite EPIRB will be provided by Inmarsat geostationary satellites as well as polar orbiting satellites. Terrestrial communications will use frequencies in the MF, HF, VHF bands. Terrestrial communications will no longer use Morse code radiotelegraphy but will employ digital selective calling, radiotelephony and narrow band direct printing (Lundberg, 1984).

There is another search and rescue satellite system operating, called Sarsat-Cospas, which has been developed by Canada, the United States, France and the Soviet Union. The Soviet Union was the first to launch a satellite under this scheme, the Cosmos 1383, in June 1982. Two Cosmos satellites and an American NOAA satellite carrying similar payloads have been credited with saving more than 60 lives. These satellites operate in

FIGURE 4.4.3

FUTURE GLOBAL MARITIME DISTRESS
AND SAFETY SYSTEM


INMARSAT'S role in global maritime distress and safety system
Urgency and safety messages
Distress relay messages for search and rescue action
Navigational or meteorological warnings
Distress alerting
EPIRB
Rescue co-ordination centre
National and International Telex and Telephone Networks
Coastguard
Port authorities
Medical assistance
Hydrographic service
Meteorological service

a polar orbit up to 1000 km above the Earth and detect signals in the 121.5 and 243 MHZ band, the international distress frequencies, as well as in the 406 MHZ band, which was recently allocated specifically for low power emergency beacon capable of being detected and located by satellites.

I.M.O. has said that it would like to see a single international distress frequency for satellite emergency beacons. That would be desirable from the perspective of the user whose equipment is likely to be cheaper than would be the case if it had to operate at two or more frequencies. The optimum system may integrate both polar-orbiting and geostationary satellites. In one scheme, Polar-orbiting satellites could also carry additional payloads, perhaps capabilities for navigation and thin-route communications, which would be especially valuable over the polar regions.

4.4.8 Safety Radio, Devices

Emergency Position Indicating Radio Beacons (EPIRB's) are now required to be carried by certain classes of ships (SOLAS 1983). These devices, when activated, transmit a signal on a number of frequencies (121.5 MHZ, 243.0 MHZ, 2182 KHZ) which can be picked up by aircraft, shore stations and more recently by satellites operating under the Sarsat-Cospas system. The devices are intended to "float free" from a vessel and are self-activating.

4.4.9 Information Deficiencies

The deficiencies in relation to communications relate to the improvement of ship to shore contact, and to the transmission of data to and from the ship.

a) As an interim solution to communications problems in the Arctic, a project aimed at enabling a ship to access the Anik D system should be carried out. The major problem will be the development of a suitable antenna and stabilization platform.

b) Reliability testing in the field of an HF modem and channel eveluation system is required.

5. SHIP DESIGN

5.1 Introduction

Since the early 1970's there has been an acceleration in the state-of-the-art of Arctic ship design. This resulted partly from the research voyages of the MANHATTAN in 1969 and 1970, and partly from the subsequent interest in commercial developments in the eastern, central and western Arctic regions. Whatever the reasons, the present understanding of design requirements and procedures is far in advance of that which existed 15 years ago.

During that time many interesting and advanced ships have been built, among those are;

- Polar Star Class,
- ARCTIC,
- R-Class and,
- Beaufort Sea Ice Management Vessels.

In addition, several future projects were developed on the drawing board, including; the Arctic Pilot Project LNG vessels and the Beaufort Sea Oil Tankers. These projects and others have pushed the boundaries of Arctic Ship Technology and encouraged research to be pursued in many areas. Those areas of ship design technology which are of most interest are:

- Structure
- Hull design and performance
- Propulsion and,
- General outfit and auxiliary systems.

Advances have been made in each of these areas. Full scale monitoring programmes have been organised to measure structural, machinery and overall ship performance, and laboratory research programmes have helped to develop a better understanding of the properties of ice the and prototype ship model testing. The following text review each of the important areas of ship design.

5.2 Structure

5.2.1 General

Arctic ship structural design is evolving and improving as a result of intense activity over the past number of years. Improvements derive from both technical advancements and from experience on the new ships.

Much has been learned about the nature of ice loads. Progress is being made on a scientific level to understand the mechanics of ice failure. Full scale measurements of ice loads have been made on several ships which have yielded an empirical description of ice forces and pressures to be used in design. The nature of these loads, the existence of a number of significant damages and the emergence of affordable nonlinear finite element analysis packages has lead to a much wider use and acceptance of plastic design. The use of 'E' grade steels which exhibit considerable plastic strength has contributed to this as well.

Use of statistical methods to establish design values is beginning to be accepted. But considerable debate continues on this topic, and more data and justification of techniques is required.

The question of hull girder design is receiving a lot of attention lately, while no measured ice ramming stresses have exceeded wave stresses and there are no reported incidiences of hull girder damage due to ice. However, impact with a large multi-year floe at over water service speed would cause bending moments well in excess of wave bending, and may have to be considered for some ships. Full scale trials, physical modelling and numerical models are all being employed to establish an understanding of the effects of ramming on the hull girder. The question of appropriate design levels is still unresolved.

This section review the present understanding of the load criteria, materials, local structure and hull girder structure for Arctic ships.

5.2.2 Load Criteria

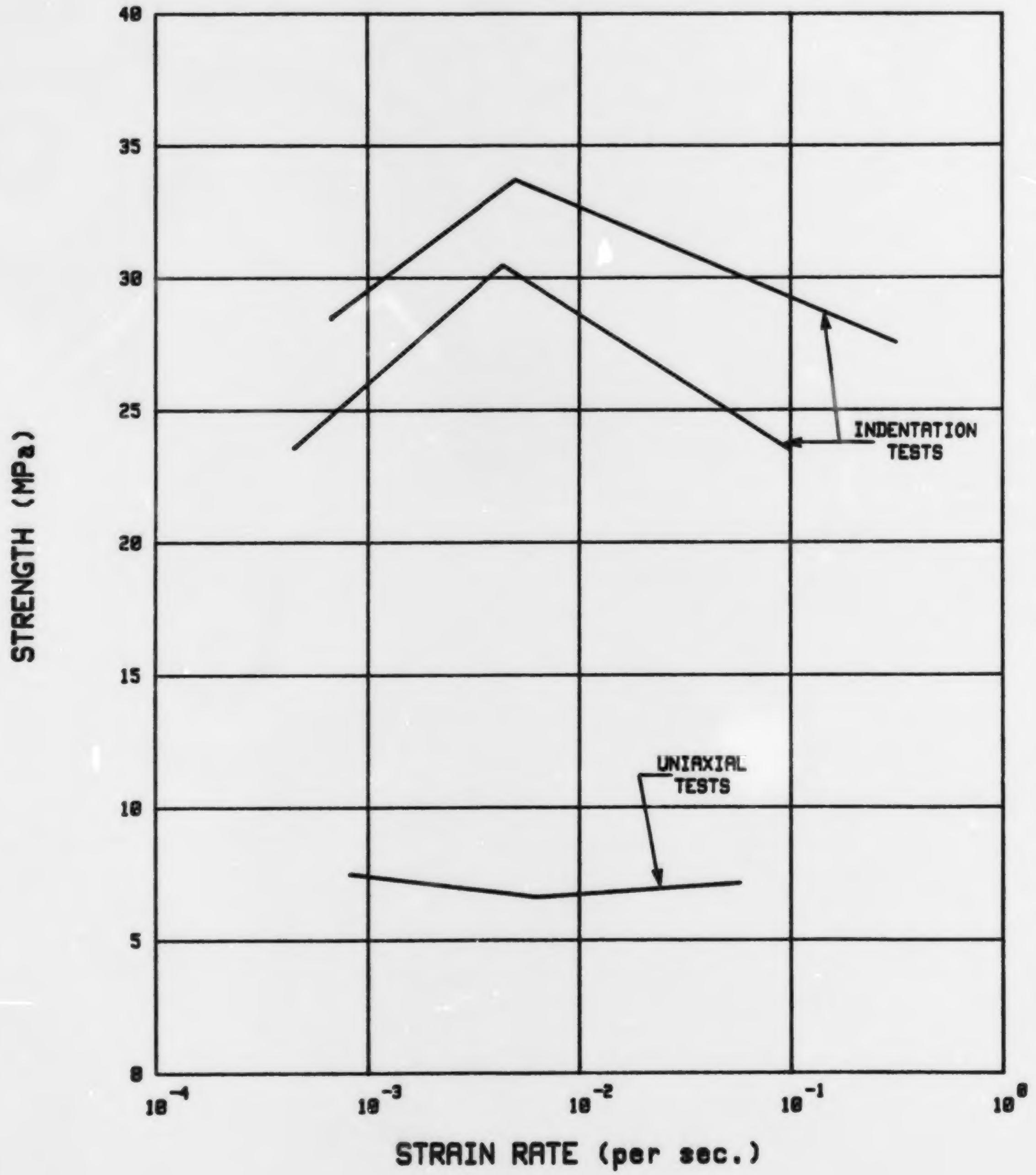
While the greatest advance in knowledge and understanding in recent years has been in the area of ice load criteria, this is still not well understood. The reason for this is that the ice failure mechanism is not fully understood.

The most current work on ice properties concerns multi-axial stress failure envelopes, shaped indentor impact tests and structure-ice interaction modelling. All of this work is based on parametric experimentation and does not yet have a firm theoretical foundation.

Figure 5.2.1 shows experimental results which compare uniaxial strength test with indentor tests for glacial ice. While ship design is more concerned with multi-year ice, the results nevertheless illustrate the considerable jump in strength from uniaxial to indentor tests. Given that

FIGURE 5.2.1

AVERAGE STRENGTH VERSUS STRAIN RATE
FOR ICEBERGS



FROM EL TAHAN et al 1984

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the uniaxial strength of multi-year ice is approximately the same as glacial ice, the indentor strength of multi-year ice may be quite high. The areas of the above tests were small and thus the pressures were higher than would be used for plate design.

There have been some attempts to formally relate mechanical ice properties to ice loads on ships (i.e. CANMAR 1985 - Ship/Ice Interaction Energies). These have typically used numerous coefficients (contact factor, scale factor, predamage factor, temperature factor, strain rate factor, aspect ratio factor, ice type factor, confinement factor) to convert the static uniaxial ice strength to a 'design' pressure. These methods have not yet proved fully successful. Work on mechanical properties continues with the hope of eventually being able to specify design loads. In the interim, design values are taken from empirical measurements and derivations.

The best current data for Arctic ships comes from three ships: the M.V. ARCTIC, M.V. KIGORIAK and the USCGC POLAR SEA. Modern systems can accurately measure ice pressures over many adjacent panels, based on frame response, and can derive total load from hull girder response. Some recent Baltic Sea data are also relevant to ice loads in level ice, and contribute to our understanding of ice failure. The following data are of most use:

Polar Sea - Thousands of events measured in first year and multi year ice on areas from .15 m^2 to 9 m^2, a Peak force of 5 MN, and a Peak Pressure of 12 MPa (.15 m^2).

Kigoriak - Hundreds of events measured in multi year ice and ridges, on areas from .2 m^2 to 5 m^2, a Peak force of 23 MN, and a Peak Pressure of 18 MPa (.2 m^2).

Many other data sources exist but for a variety of reasons are only of peripheral interest. Problematic data includes;

Varsta Gauges (Kigoriak, Sisu)	- measurement area is too small.
Pressure Gauges (Louis, S. St-Laurent)	- measurement area is too small.
Strain Gauges (M.V. Arctic, Radisson)	- non-contiguous, poor calibration, light ice conditions.
APOA (Several)	- indentation tests, low strain rate, confidential.
Geotech Indentor Tests (Glacial and Multi year)	- too few data points, confidential.
Offshore Island Measurements (Several)	- low strain rate, few data points, confidential.

Figure 5.2.2 shows peak values of pressure versus area of measurement for the important data sets. Figure 5.2.3 (Sanderson, 1986) gives a summary of pressure/area data from ships, offshore structures and laboratory data. The envelope curve above the data has the equation:

$$p = 11.5\ A^{-0.5} \quad (\text{MPa, } m^2)$$

At a typical plate design area of .15 m^2, Sanderson's envelope equation gives a pressure 29.7 MPa, which is well above most design ice pressures. The question of establishing an appropriate design pressure which is consistent with field measurements of pressure needs further investigation.

One way of deriving ice pressures is to examine the experience of ships such as the KIGORIAK, POLAR SEA, TERRY FOX, KALVIK, and M.V. ARCTIC. This base of experience (some with damage and some without) can be used to infer appropriate design ice pressures. The regulatory proposal by CANMAR is an example of this. CANMAR proceeded by assuming the nature of the ice load (i.e., aspect ratio, pressure/area effect, amount of bridging) and then, using the Kigoriak scantlings, derived the magnitude of the ice pressure. While this approach may result in incorrect extrapolation, it does at least ensure that design will concur based on experience. By incorrect extrapolation, is meant that if the ship behaviour is misjudged (i.e. assume elastic behaviour when in fact some minor yielding has occurred), then the inferred ice load will be incorrect, and design for other structural configurations will also be incorrect.

This again emphasizes the need to know the 'true' nature of ice pressures. This can best be accomplished by searching for a definition of ice load that is consistent with all available information.

5.2.3 Materials

The selection of steel grades suitable for use in ships' structures which are exposed to very low temperatures has been under extensive study recently by the classification societies, regulatory authorities and others. Draft regulations and proposals have been made and some classification societies have already introduced a materials section in their rules for Arctic class vessels (Lloyds Register of Shipping; American Bureau of Shipping; Bureau Veritas).

The toughness of steel is directly related to temperature, and the effective toughness to the rate of loading, as shown by Figure 5.2.4. In the absence of adequate toughness; the presence of a flaw of sufficient size and a stress of sufficient magnitude to cause crack propagation, steel will fracture in a brittle manner without any warning of an impending failure. This has resulted in the loss of ships.

FIGURE 5.2.2

SHIPBOARD MEASUREMENTS OF PRESSURE VERSUS AREA

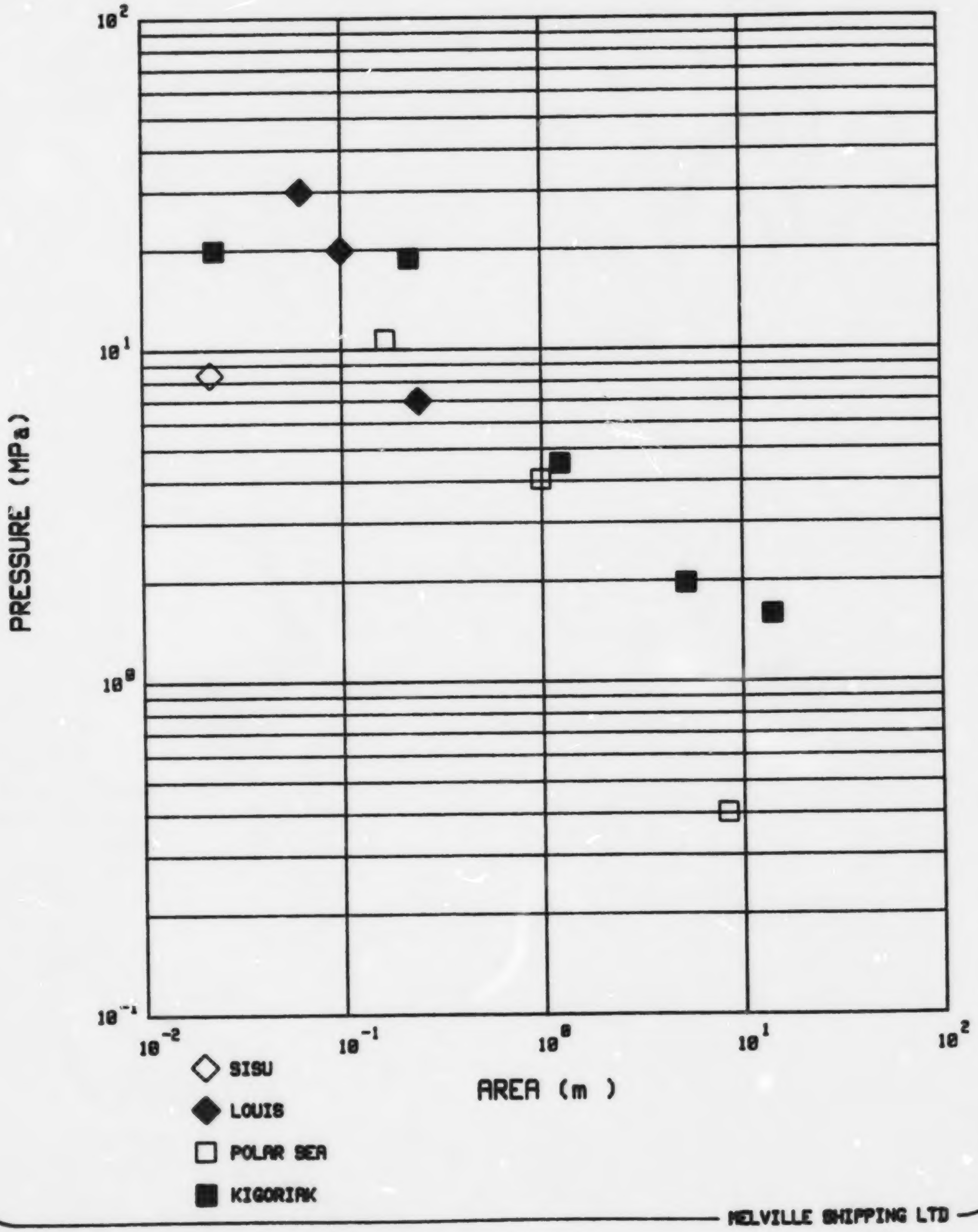

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FIGURE 5.2.3

PRESSURE-AREA DATA SUMMARY
(SANDERSON 1986)

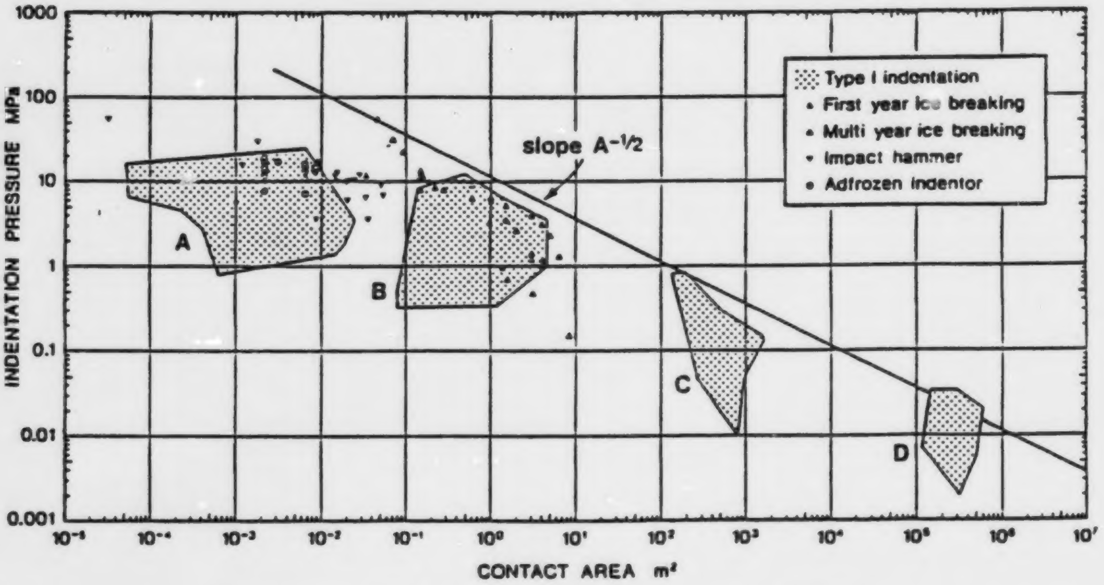


Figure 3 General trend of pressure-area curve, with data groups.

A: Laboratory tests

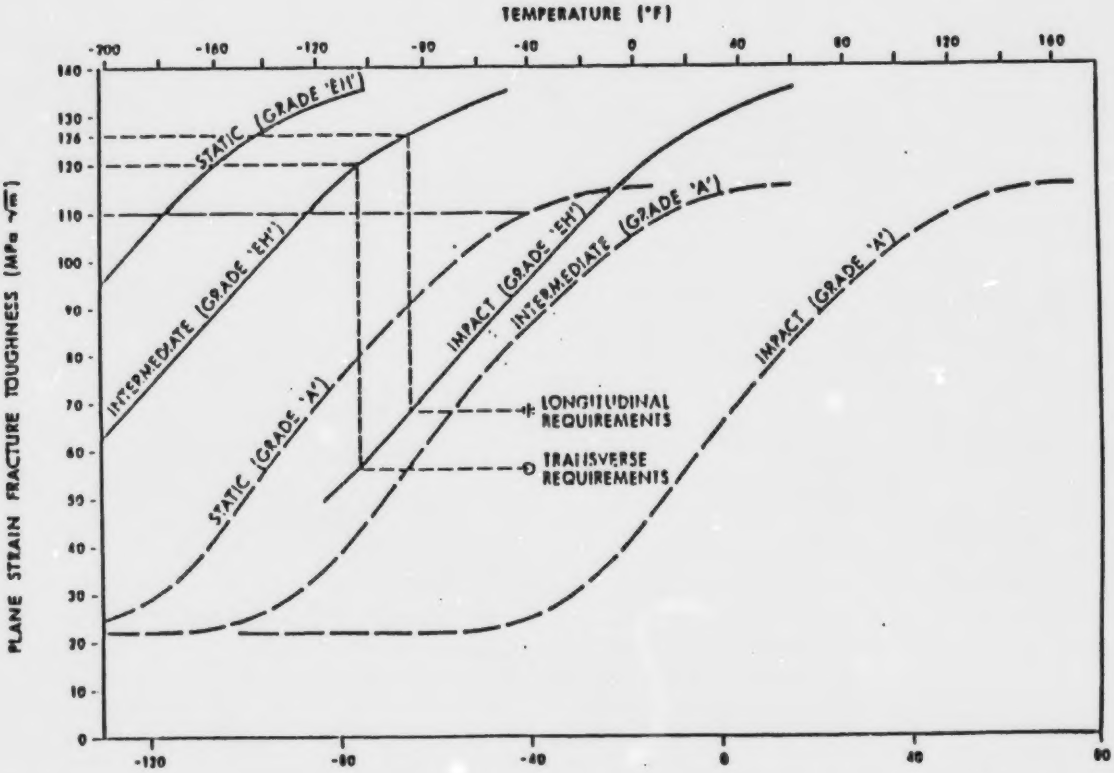
B: Medium-scale in situ tests, lighthouses and bridge piers

C: Full-scale Arctic islands and structures

D: Meso-scale models.

FIGURE 5.2.4

GRADE "EH" STEEL FRACTURE TOUGHNESS CURVES



Brittle fracture of steels first became of importance to shipbuilders and designers when all-welded ships were introduced in the 1940's. Several of these early all-welded ships broke in half before they had ever entered service, even when the temperature of the steel was well above 0°C. Subsequent investigations in the late 1940's and early 1950's identified the failures to be brittle fracture brought about by a combination of poor steel quality, poor welding, poor design and, in some instances, high stresses. Although high stresses are an essential characteristic of the failures, the stresses may be due to stress concentrations brought about by poor design, flaws in the material or defects introduced during construction (Lloyds Register of Shipping).

The causes of brittle fracture have now been established and the relationship between the cause of fracture, the toughness of the material, flaw size and shape, loading rate of the structure and temperature are understood. From this understanding, the reliability of structures has been greatly increased and materials and welding techniques developed to improve the toughness of the steel and structures when at low temperature (McLean, 1983).

Two conferences/study sessions concerning materials to be used for Arctic engineering applications have been held recently in Ottawa, both were organised by CANMET. In October 1983, a study session on "Fracture Toughness Evaluation Of Steels for Arctic Marine Use" was held and, in July, 1985, a conference on "Steels for Offshore and Arctic Applications" also met in Ottawa. Both meetings attracted contributors not only from within Canada but also from overseas and papers which outlined the present state of knowledge on these subjects were presented. While this review extensively references papers presented at both proceedings, all papers presented at the two conferences are highly recommended as relevant to the subject of 'Arctic steel'.

5.2.3.1 Selection

At present there is a lack of consensus in regard to appropriate steel grades for Arctic vessels. The general opinion of operators of Arctic shipping is that the steels used in the present generation of ships are mostly adequate. This opinion is based on the generally satisfactory performance of Arctic vessels, although, it should be noted, the sum total of experience in the Arctic is much smaller than shipping in warmer waters. The research community tend towards the view that some of the more advanced steels, with very high toughness at low temperature, are appropriate for critical portions of ship structures. In interpreting the latest research, the regulators have been making their requirements increasingly more stringent.

A good part of the lack of consensus can be attributed to lack of data. This becomes apparent when the primary factors are reviewed:

a) **Temperature** data for the Arctic are sparse, and their relationship with actual steel temperatures in the ship structure is not well understood.

b) **Stress Levels** experienced under ice loads are not well documented. However, it does appear general stress levels are likely to be significantly less than would be encountered in open waters due to wave loading.

c) **The Fracture Toughness** is known to be sensitive to rate of loading. The few data that are available for ice impact suggest maximum strain rates of the order of 10^{-2} 1/s. This is broadly equivalent to strain rates typical of hull loading during slamming in rough seas, usually categorized as an intermediate rate.

A survey conducted by Lloyds (Rapo, 1983) of ships operating, or designed for operation, in the Arctic, indicated that the steel grades varied from Grade A to Grade EH36. The practice appears to be to follow traditional steel selection procedures, except that materials with higher notch toughness than usual are selected.

Trudeau (1983) has summarized recent operational experience of winter shipping, particularly in the Gulf of St. Lawrence. In the Arctic, one of the most serious fractures occurred on the SIR JOHN A. MACDONALD. The failure, in the form of a crack several meters long, resulted from ice impact in the Beaufort Sea. The affected plate was Grade C steel. Cracks have been detected on the M.V. ARCTIC, as have numerous dents. Fatigue cracks were found to be present in the bilge keel region near welds.

At the time of the inspections revealing these cracks (early 80's) the M.V. ARCTIC was constructed of A grade steel, except for part of the sheer strake and deck. The presence of these cracks led to a number of studies in which the steel grades used in the construction of the M.V. ARCTIC were re-evaluated. Steel grades in parts of the hull structure were upgraded with steels of higher notch toughness.

Incidents of weld corrosion, on the SIR HUMPHREY GILBERT and the SIR JOHN A. MACDONALD, have been documented (Gilmour, 1980).

There has been a considerable amount of work carried out in recent years of the behaviour of structures and structural steel under different loading conditions when at low temperature. This work is reflected in the papers of recent conferences, (Pellini, 1983). There are two schools which represent the philosophies, "design-by-rule" and "design-by-analysis".

a) **Design-by-rule** is principally supported by classification societies and regulatory authorities. This approach only requires the designer to consider service temperature and to select steel grades which are notch tough by Charpy Impact Test methods. The designer is not required to consider in any detail the type of loading which the structure will experience in service or the validity of the test methods which are used to select the steel, or to perform any calculations to estimate the probable reliability of the structure.

A number of organizations have proposed rules for the selection of steel grade (Lloyds, ABS). Similar rules have been proposed as an amendment to the Arctic Shipping Pollution Prevention Regulations. These rules are a modified version of International Association Of Classification Societies (IACS) recommendations.

b) **Design-by-analysis** is far more rigorous, requiring the designer to consider each part of the structure with reference to the whole, decide whether the structure is of primary, secondary or tertiary importance, and to consider the load regimes which may be applied when in service. Fracture mechanics approaches are then used to determine the reliability of the structure and the characteristics of the materials which must be used (Tyson, 1982). This approach imposes a large responsibility on the designer but may provide an economical design which is more reliable than that produced by the "design by-rule" approach (Lereim, 1983).

If the 'design-by-analysis' approach to ship design is taken, the work which has been carried out by researchers in the field of fracture mechanics must be interpreted by the ship designer in the context of ships' structures and the type of loading experienced by ships. This will have a significant influence on the materials to be selected for various parts of the ship. In the bow of the vessel, shock loads must be considered to be normal due to impact with the ice and the presence of small fatigue cracks must be assumed. As fatigue cracks will have a very sharp tip, the stress concentration at the tip will be considerably greater than that at the tip of the vee notch of a Charpy test specimen. A factor of five has been estimated (Nibbering, 1983). Therefore, the crack arrest properties of the material must be selected on the basis that brittle fracture conditions in the bow are present. Cracks in the bow, even the most severe, are unlikely to result in a failure of the primary structure. Therefore, crack arrest properties of the material are the most important design consideration.

The loading conditions outside the bow region are likely to be more moderate and shock loads will not normally occur. The midbody region of the ship will experience vibrations excited by shocks at the bow but the vibratory stresses will have very much longer rise times than shock induced stresses and, therefore, will be of less risk to initiate a fracture. However, brittle fractures, sufficient to cause failures in the primary structure, have been experienced in the midbody of ships. Although the strain rate is lower, static stresses may be high and may be made higher by the excitation of natural frequencies of vibration (Nibbering, 1983).

As midbody damage is potentially more catastrophic than damage to the bow, materials and welding techniques must be selected and designed to prevent both crack initiation and crack propagation. Prevention of crack initiation is probably not a practical alternative. It is neither practically nor commercially possible to eliminate all possible seats of crack initiation in such a complex welded structure as a ship, nor to ensure that the materials and workmanship are completely free from defects. Therefore, if small cracks and defects are accepted to be inevitable the materials must have crack arrest properties to prevent propagation (Nibbering, 1983; Tomin, 1983).

Unfortunately, the vital parameter of toughness is very difficult to quantify by a single test. Therefore, a variety of tests have been developed to determine the toughness of the material in a particular mode of failure. The test which is required by the classification societies to determine toughness, is the Chappy Vee Notch Impact Test (CVN). This test has come under increasing criticism lately, as the understanding increases of the mechanism of brittle fracture. However, the test is simple to perform and provides a qualitative assessment of toughness between different steels. Other tests such as the CTOD test, Pellini drop weight test, tear tests, etc. all provide as good, if not better measures of material toughness, but there is no common agreement in industry on which test should become the standard. In the meantime the CVN test, at least in the shipbuilding industry, provides the standard test for toughness (Pellini, 1983; Pisarski, 1983).

The recent increase in the research and development of steel grades and welding techniques suitable for use in structures exposed to very low temperatures is due largely to a requirement to transport and store gases and liquids at very low temperatures, and to a growth of both land and marine projects in the cold regions of the world. There is now available to shipbuilders a large variety of steels which are notch tough at low temperature and are suitable for Arctic ships. These steels range from the normalised and controlled rolled steels to the high strength quenched and tempered steels (Kozasu, 1983; Stern, 1985).

5.2.3.2 Welding

In the context of the reliability of the structure of an Arctic ship, assuming suitable steel grades have been selected for the service temperature, the most important component is the welding of the steel.

Welding of Arctic steels for ships must be considered discretely, that is, the loading conditions and service conditions for welds in ships are different from there, of say, pipelines and fixed land and marine structures. There are, of course, common areas and common approaches, but welds in ships are unique as they must withstand the corrosive effects of seawater on one side and possibly cargo on the other; impact loads and bending stresses during icebreaking operations; a variety of static stresses due to cargo and ballast distribution and other loads and stresses, both static and dynamic, when working cargo in Arctic ports.

It is not possible to carry out 100% inspection of the structural welds in a ships hull due to the general complexity of the structure. Sighting of virtually all welds may be possible but poor welds must often be accepted due to lack of access for the welder to provide high quality work. Neither sighting the weld nor non-destructive testing will indicate the hardness of the Heat Affected Zone (HAZ) nor the toughness of the weld material in HAZ. The properties of the weld metal are determined by the selection of the consumable, and the properties of the HAZ and the deposited material are dependent upon the skill of the welder and the procedure laid down by the welding engineer. The biggest variable is the skill of the welder, especially when welding in confined spaces in the ship. However, the knowledge of the welding engineer is also important.

There is little point in the designer concerning himself with the selection of relatively sophisticated and expensive materials to improve the reliability of the structure, if flaws and other defects are allowed to be introduced by the lack of quality control, as well as from the inappropriate selection of welding consumables and techniques, in particular the heat used and rate of deposition of the material (Pellini, 1983).

To place the importance of the fabricator's role in context in insuring reliability of the structure, approximately 95% of all defects in a structure fail from defects within the welded zone and it's from these defects that brittle fractures will initiate (Pense, 1983).

The fracture properties of welds are determined by their microstructure. Welding consumables have low carbon content compared to the parent plate to prevent the weld from cracking during solidification and cooling, and other alloying elements are added to weld metal to provide the necessary strength and to offset the low carbon content. The fine microstructure of the weld is due to the rapid cooling rate, and results in better fracture properties than normal pearlitic steels in the as-rolled and normalised condition (Pellini, 1983; Price, 1984).

For high strength quenched and tempered steels, the parent metal and welds tend to have similar fine grained microstructures and hence similar fracture properties.

The method of weld metal deposition, including the rate, the number of passes, heat input and electrode size and electrode compaction have an affect on the fracture toughness of the weld, and variations of weld toughness may be greater than that of the parent plate. Therefore, caution must be exercised not to impair the toughness properties of the weld when using large electrodes and fast rates of deposition, in the interests of economy.

The corrosion of welded joints exposed to seawater in Arctic ships has become prevalent in recent years. Accelerated corrosion of the weld metal and of the heat affected zone of welds has been noted in Canada, Finland and Russia. The reason for this corrosion can be due to nobility between the weld metal and the base metal due either to chemical composition or to differences in microstructure and hardness, i.e., chemical corrosion or stress corrosion. Both types of corrosion are accelerated by the oxygen rich waters of the Arctic and the scouring action of the corrosion sites by ice. The effect of corrosion is either to cause local thinning of the plate or, more importantly, to produce stress concentrations from which fatigue cracks may initiate and propagate. This latter effect is compounded by the reduction of the fatigue strength of the steel when immersed in sea water.

In Canada and Japan, work is presently in progress to study weld line corrosion in ships under Arctic conditions. This work involves the deposition of different weld metals on an Arctic class ship and measurements of the rate of wastage over several years. At the same time the ship conditions will be duplicated by laboratory experiments to speed up the study.

In Finland, the use of a capping of weld filler material containing 0.6% copper and 0.2 - 0.25% silicon, and adjustments to the base weld and plate chemistry, have been used on Russian icebreakers with success (Rasanen, 1983).

Heat affected zone corrosion has been recorded in high managanese steel used in icebreaker shell plating. It was further noted that corrosion increased with increasing manganese and silicon content and with decreasing weld heat input and working temperature. It has been concluded that HAZ corrosion can be reduced by limiting the manganese content of the base steel to less than 1.1% and silicon to less than 0.35%. When welding without preheating, heat input greater than 12 kJ/cm should be used. In addition toughness can be improved by micro-alloying with Al, Va and Nb (Rasanen, 1983).

Fusion line corrosion has been contained by reducing the sulphur content of the base metal to below 0.01% and alloying cerium. This type of corrosion, sometimes called knife edge corrosion, is associated with the liquidation of sulphides and impurity films which were formed at the boundary of the parent austenite in the fusion line (Rasanen, 1983)

5.2.4 Local Structure

5.2.4.1 Plating

The plating generally makes the largest contribution to the structural weight of most ships, and together with the frames and stringers forms stiffened panels. While lightness can sometimes be attained by increased framing and reduced plate thickness, this is usually accompanied by increased fabrication cost. There have been a number of studies investigating a variety of configurations with the aim of seeking optimum solutions.

The most elementary approach to plate design is based on small deflection theory. This theory yields accurate estimates of deflection and bending stress for displacement much less than the plate thickness. However small deflection theory is not adequate for predicting the ultimate capacity of the plate, primarily because membrane action is ignored in the theory. This has led to the development of large deflection theory, in which the increase in load-carrying capacity due to membrane action is accounted for. Recent analyses and experiments have investigated plate behaviour beyond the elastic limit, including both bending and membrane action.

When plate deformation is well into the plastic range and membrane action is dominant, the distinction between simply supported and fixed edges, in terms of rotational restraint, becomes less important. However the boundary conditions for in-plane behaviour become important. Except for a few areas on the ship structure, it is not likely that the boundary condition of zero inward movement is appropriate. Some approximations are necessary.

Design of plate elements and frames are often governed by a limiting permanent set, except when instability, for example, tripping of stiffeners, is a consideration. The establishment of appropriate limiting values of permanent set is difficult and incorporates some degree of subjectivity.

The ultimate strength of plating can be many times larger than the yield strength, due to the membrane behaviour at large deflections. While both deflections and rupture strength are of concern in ships, it is necessary to define the acceptable limits of both. A number of excellent papers have been written (Jones, 1976; Ratzlaff, 1986) which examine the behaviour of flat plates under uniform lateral loading.

Figure 5.2.5 shows plate behaviour as a plot of load versus deflection. In this case, the load is given as the ratio of pressure, P, to a reference pressure P . (Note: P is a convenient point of reference called the collapse pressure and is equal to the pressure that would cause three plastic hinges if no membrane effects occurred). The deflection is given as the ratio of the deflection w to the thickness t. The significance of the paper is in the fact that the experimental test results of Young shows a behaviour in which the plate yields at the point labelled E. An edge hinge forms at point 'A' and then membrane action takes over as the experimental results approach line N which represents ideal plastic membrane behaviour.

This thin plate was capable of withstanding a load seven times larger than the 'three hinge' load (point 'C') at a deflection equal to nearly four times the thickness. For thin plates, at least, the 'three hinge' case does not occur. For thick plates, such as are found on icebreaking ships, the line F, including the 'three-hinge' point C, moves to the left, while the line N is unchanged. This suggests that thick plates may have to form three hinges before they can activate full membrane behaviour.

Depending on the type of behaviour which is acceptable, different equations will specify thickness of the plate. These are shown in Table 5.2.1. The details of each equation may be obtained from the sources indentified in the table.

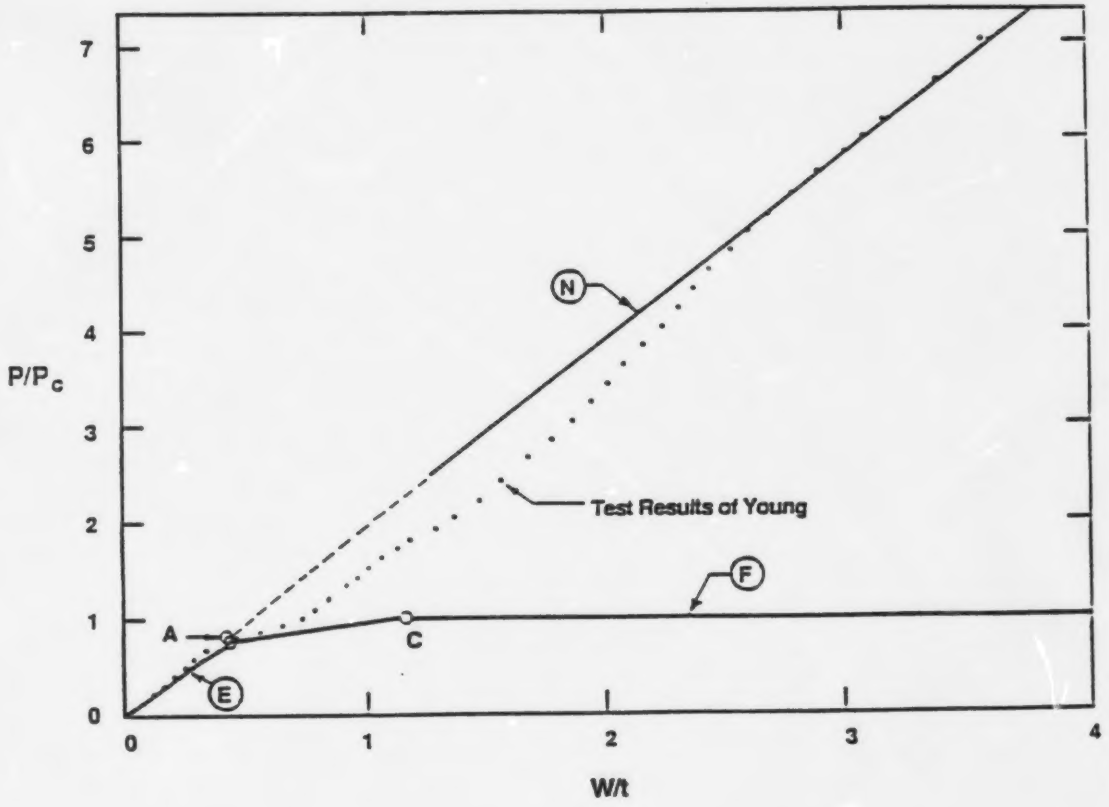
5.2.4.2 Framing

Framing supports the shell plate, and individual frames act like beams, resisting the loads on the shell by both bending and shear. Most serious structural damage due to ice pressure has involved failure in the frames. This type of failure often manifests itself as tripping of frames and shear yield in deep frames. Frames have several components:

. the shell plate which acts as a flange
. a web
. an internal flange (or bulb) (optional)
. end brackets (optional)
. tripping brackets (optional)
. cutouts (optional)

FIGURE 5.2.5

SHELL PLATE BEHAVIOURAL DOMAIN
(RATZLAFF AND KENNEDY 1986)



Ⓔ Elastic flexure with elastic membrane, up to complete formation of edge hinge.

Ⓕ Elastic flexure without membrane, then 1st hinge, then 3 hinge collapse point C, all without membrane

Ⓝ Ideal plastic membrane action, valid after all hinges and flexure has been "pulled out".

Test results of Young - Experimental Data showing a 1st hinge but then membrane behaviour and not 3 hinge collapse.

TABLE 5.2.1

COMPARISON OF VARIOUS PLATE DESIGN FORMULAE

	CONDITION	EQUATION	PERMANENT SET (w)	REFERENCE & DATE	COMMENTS
1.	1st Yield	$t = .707\ s\ (P/f)^{.5}$	$w = 0$	Timoshenko (1959)	Elastic beam theory
2.	1st Yield	$t = .667\ s\ (P/f)^{.5}$	$w = 0$	Timoshenko (1959)	Elastic beam theory, Poissons effect included
3.	1 Hinge	$t = .544\ s\ (P/f)^{.5}$	$w = .7\ s^2 f/(tE)$	Hughes (1983)	Plastic edge hinge, Poissons effect included
4.	1 Hinge	$t = .32\ s\ P^{.75} E^{.25}/f$	$w = .005\ s$	Clarkson (1956)	w equivanent to welding deformations
5.	2 Hinge	$t = .397\ s\ (P.f)^{.5}$	$w = t$	Hughes (1983)	Aspect ratio = .25. Edges free to pull in.
6.	3 Hinge	$t = .5\ s\ (P/f)^{.5}$	unspecified	Johansson (1967)	Beam theory
7.	3 Hinge + Membrane	$t = .353\ s\ (P/f)^{.5}$	$w = t$	Jones (1976)	Beam theory
8.	Membrane	$t = 1.25\ s\ P/f$	$w = .1\ s$	Jones (1976)	For aspect ratios of 2:1 and greater
9.	Membrane	$t = 1.01\ s\ P/f$	$w = .1\ s$	Ratzlaff/ Kennendy (1986)	Poissons ratio and edge angle included.

With so many possible configurations, there are also a large number of failure mechanisms and therefore a large number of strength and/or design equations.

Figure 5.2.6 (Hughes, 1983) shows a number of collapse mechanisms for a single span frame, if only plastic moment hinge formation is considered. In fact hinges do not form so simply. Figure 5.2.7 from (Hakala, 1980) shows the spreading plastification of a frame in the region of a bracket. Another common failure mechanism, called lateral torsion buckling, is shown on Figure 5.2.8 (Canmar, 1980). This mechanism is enhanced when the cross section is non symmetrical.

Frames are also susceptible to shear failure and local web crippling. As a result many checks are necessary during design to ensure adequacy.

5.2.4.3 Present Regulatory Position

The CASPPR Hull Structure Requirements are currently under extensive review and are to be updated soon. Several recent proposals have been made by Classification Societies and others, notably; American Bureau of Shipping, Lloyd's Register, Det Norske Veritas, CANMAR, and the U.S. Ship Structures Committee.

The Soviet Union and the Finnish-Swedish Board of Navigation have each recently issued revised regulations. However, only the upcoming CASPPR rules will reflect all of the recently gained full scale experimental data and experience.

Table 5.2.2 presents a comparison of various approaches to structural requirements. It is clear that a very wide range of approaches are employed. In most cases the design pressure is (artificially) low, while elastic or 3-hinge plastic design is employed for both plating and framing. None of the methods explicitly employs probabilistic design (although it is implicit in ACL's and possibly others). The influence of displacement, power, frame spacing and hull angles is different in all methods. The ACL proposal is unique in specifying shell plate based on membrane strength and statistically extreme ice pressures. The ACL and CANMAR proposal (for CASPPR update) are together unique in calling for frame design based on allowable shear area. Figure 5.2.9 compares both design pressures and plate thickness (for the highest class). The fact that the two quantities do not follow similar trends is indicative of the diverse (and empirical) approaches to design.

5.2.5 Hull Girder Structure

Traditional methods of hull girder bending design for open water service involve balancing the ship on a 'static' wave, the height of which is usually expressed as a function of the ship's length. The hull girder design stress are then calculated assuming the girder behaves as a simple beam.

FIGURE 5.2.6

COLLAPSE LOADS FOR SINGLE-SPAN BEAMS
(HUGHES 1983)

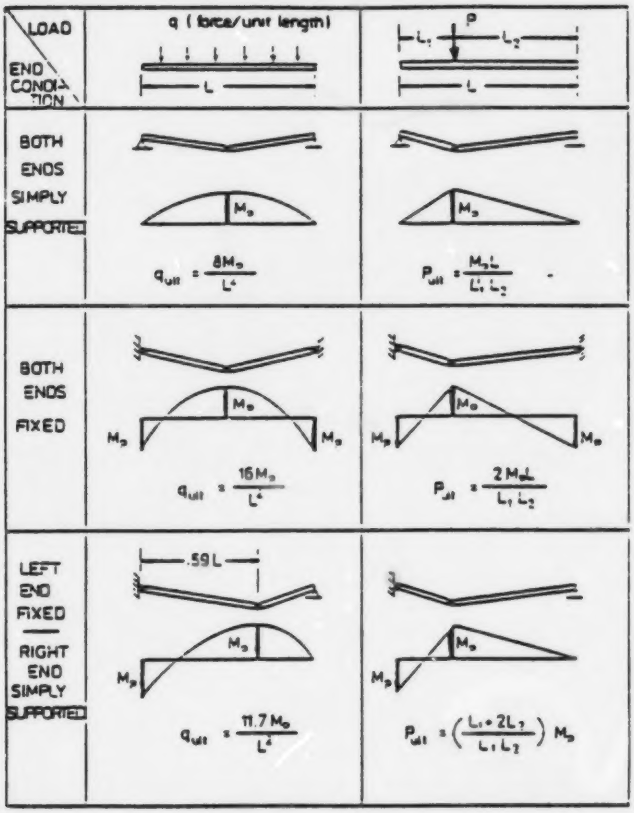

LOAD
END CONDITION
q (force/unit length)
L
P
L_1
L_2
L
BOTH ENDS SIMPLY SUPPORTED
M_p
$q_{ult} = \frac{8M_p}{L^2}$
M_p
$P_{ult} = \frac{M_p L}{L_1 L_2}$
BOTH ENDS FIXED
M_p
M_p
M_p
$q_{ult} = \frac{16 M_p}{L^2}$
M_p
M_p
M_p
$P_{ult} = \frac{2 M_p L}{L_1 L_2}$
LEFT END FIXED
RIGHT END SIMPLY SUPPORTED
.59 L
M_p
M_p
$q_{ult} = \frac{11.7 M_p}{L^2}$
M_p
M_p
$P_{ult} = \left(\frac{L_1 + 2L_2}{L_1 L_2}\right) M_p$

FIGURE 5.2.7

SPREADING PLASTIFICATION OF A FRAME WITH BRACKET (HAKULA 1980)

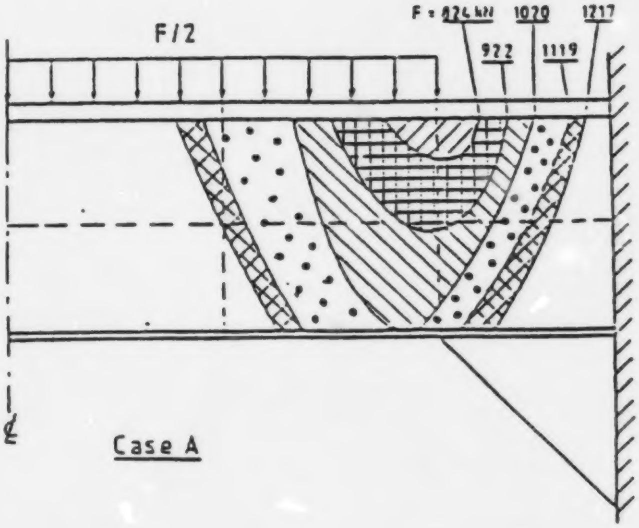
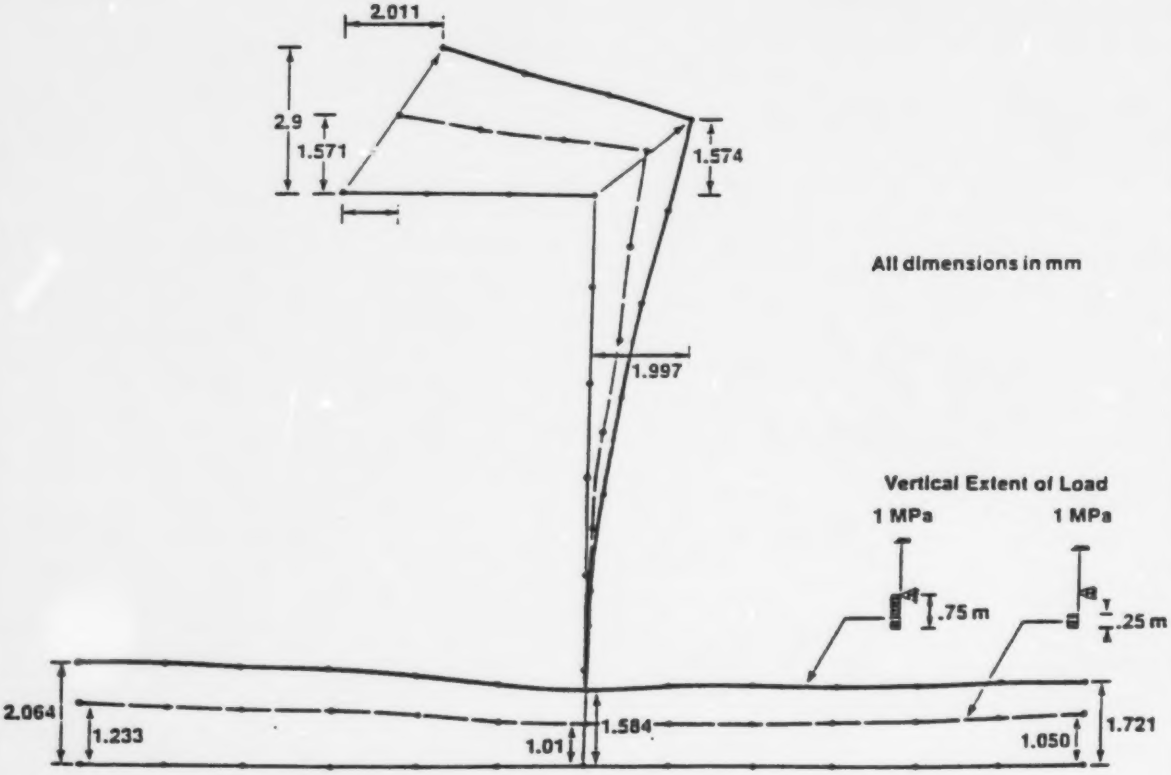

F/2
F = 874 kN
922
1070
1119
1217
℄
Case A

FIGURE 5.2.8

ELASTIC DEFORMATION OF A FRAME IN THE MIDBODY OF THE MV ARCTIC (CANMAR 1985)


2.011
2.9
1.571
1.574
All dimensions in mm
1.997
Vertical Extent of Load
1 MPa
1 MPa
.75 m
.25 m
2.064
1.233
1.01
1.584
1.050
1.721

NOTE THE TENDANCY TOWARD
LATERAL BUCKLING

TABLE 5.2.2

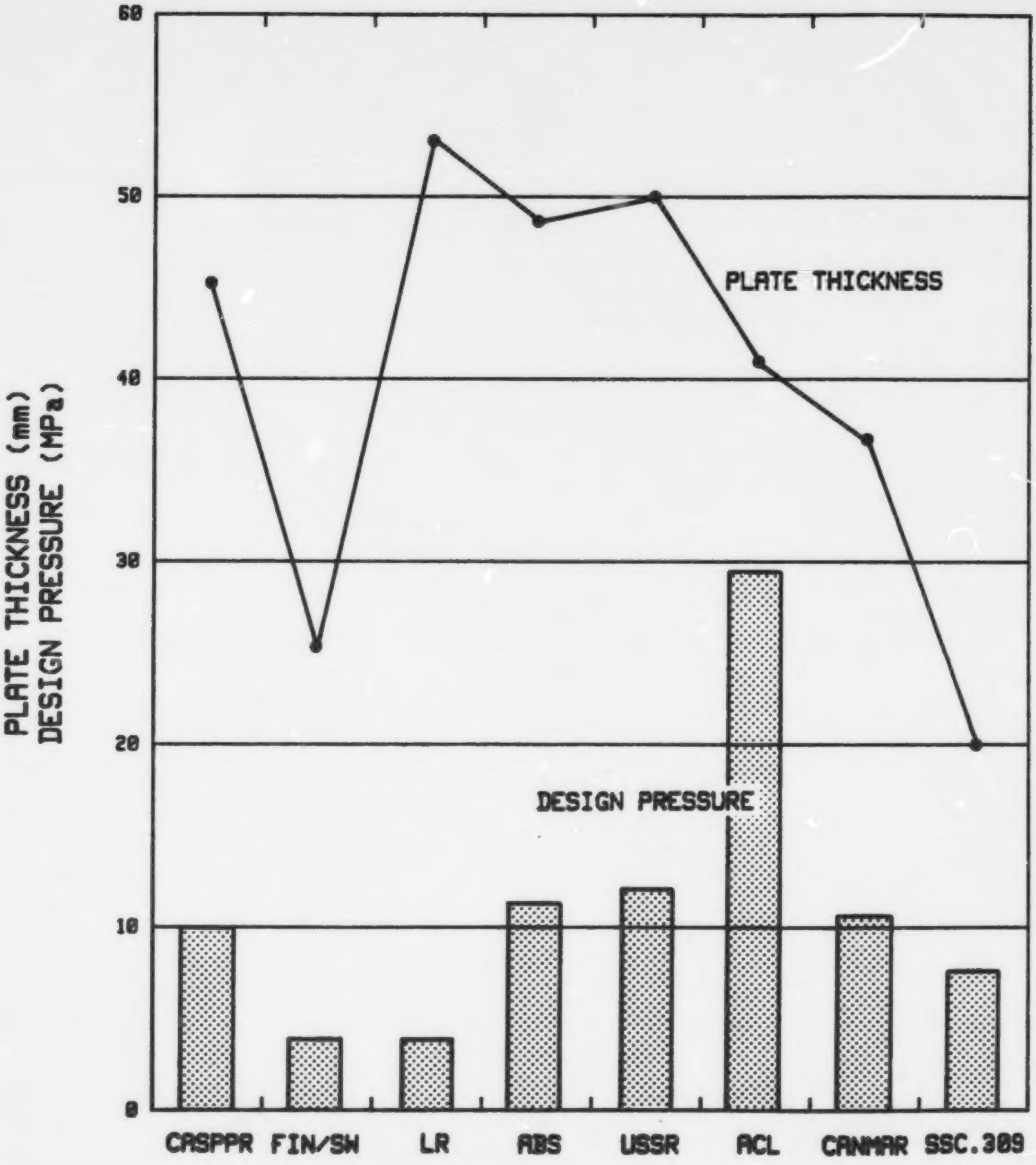
COMPARISON OF REGULATORY REQUIREMENTS

	RULE or PROPOSAL			
ITEM	CASPPR (1971)	FINN/SWED (1984)	LLOYD'S Prop. (1983)	ABS (1983)
1. No. of Classes	9 Arctic + 4 Baltic	4 Baltic	4 Arctic + 4 Baltic	5 Arctic + 3 Baltic
2. Highest Class	10	1A SUPER	AC3	A5
3. Design Ice Pressure Procedure (MPa)	from Table II	P=co*cl*ca*po depends on D,N,spacings	from Table	P=Po*Fo depends on D,N,angles
Example Ship	P=10.34	P=3.69	P=3.92	P=11.78
4. Shell Plate Formula	t=.667*s*√(P/f)	t=.578*s*√(P/f)+2	t=.5*s*c*√(P/f)+9	t=.6*s*√(P/f)+6
Example Ship	t=45.21	t=25.4	t=52.8	t=49.4
5. Frame Design Method	Section Modulus	Section Modulus	Section Modulus	Section Modulus
Example Ship	Z=862 cm3	Z=215 cm3	Z=523 cm3	z=418 cm3

	RULE or PROPOSAL			
ITEM	RUSSIAN (1982)	ACL Prop. (1986)	CANMAR Prop. (1986)	SSC-309 (1981)
1. No. of Classes	4 Icebreaking +5 Navigation	4 Arctic +4 Baltic	4 Arctic +4 Baltic	–
2. Highest Class	LL1	U	U	–
3. Design Ice Pressure Procedure (MPa)	P=6.88*D^1/6 *(1+.003*N)	P=(4.6*D^1/12* kp^.023-.7)/√s	P=(7.6+.0124* FMAX)/(2*s)	P=[p(T,S)*ft*fr]
Example Ship	P=12.58	P=29.6	P=10.88	P=7.45
4. Shell Plate Formula	t=.6*s*√(p/f)+6	t=1.25*s*Pp/f	t=.5*s*√(BPP/f)+2	t=.353*s*√(P/f)
Example Ship	t=50.8	t=41mm	t=36.8mm	t=20.3mm
5. Frame Design Method	Section Modulus	Shear Area	Shear Area	Section Modulus
Example Ship	Z=679 cm3	A=140 cm2	A=125 cm2	Z=517 cm3
Example Ship: Takes on Highest Class		D=25kT	L=160m	N=22MW
		s=400mm	b=1000mm	Bow Region
	B=24	alpha=40deg	beta=60deg	f=350 MPa
Note: Framing Design is complex in all methods. Rigorous comparissons depend on many details.				

FIGURE 5.2.9

COMPARISON OF DESIGN PRESSURE AND PLATE THICKNESS FOR THE HIGHEST CLASS



s = 400mm
f = 360MPa

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This traditional approach has evolved over time and has generally yielded satisfactory designs. However, hull girder response to ice impact is outside the scope of traditional methods. The primary reasons for this are the very limited experience of ship-ice interaction and the transient nature of the problem. In the ramming mode the dynamic response characteristics of the hull girder become important. This mode bears some resemblance to the more familiar 'slamming' problem in which large hydrodynamic forces are induced as large changes in the breadth of immersed cross section occur as the ship moves vertically, particularly in the region of the bow.

Slamming results in a large deceleration of the bow and excites vertical bending vibration modes, particularly the two-node mode but also the higher modes. Ship dynamics during ice ramming display similar characteristics. However, there are some differences. Depending on the strength of the ram the ship tends to partially 'beach' itself. Therefore the free-free beam dynamics model no longer holds; a more appropriate model is that of a pinned-free beam. Furthermore, the added mass and hydrodynamic damping are likely to play a smaller role in the case of ice ramming.

For the purposes of hull girder design the major effort has been towards the development of empirical expressions relating the maximum/ship/ice impact forces. The "design" case of concern in the Canadian Arctic is the ramming of large old ice floes and ice islands.

Five ships which have yielded some full scale data on total force and hull girder stress due to ramming heavy ice. These are:

KIGORIAK:	218 measured rams in July and October 1983.	Highest force of 25 MN @ 4.5 m/s, in grounded multi-year ice.
ROBERT LEMEUR:	116 measured rams in June 1983.	Highest force of 16 MN @ 3.2 m/s in a grounded first ridge.
POLAR SEA:	40 measured rams in October 1985.	Highest force of 25 MN @ 4.5 m/s in multiyear ice.
M.V. ARCTIC:	143 measured rams in June 1984.	Highest force of 23 MN @ 2 m/s in multiyear ice.
MANHATTAN:	2 measured rams in October 1969.	Highest force of 72 MN @ 2.5 m/s against a (non-infinite) ice island (force is estimated to be only 50-70% of value if ice island had ben "infinite").

FIGURE 5.2.10

FORCE VERSUS DISPLACEMENT FOR HEAD ON SHIP/ICE IMPACT

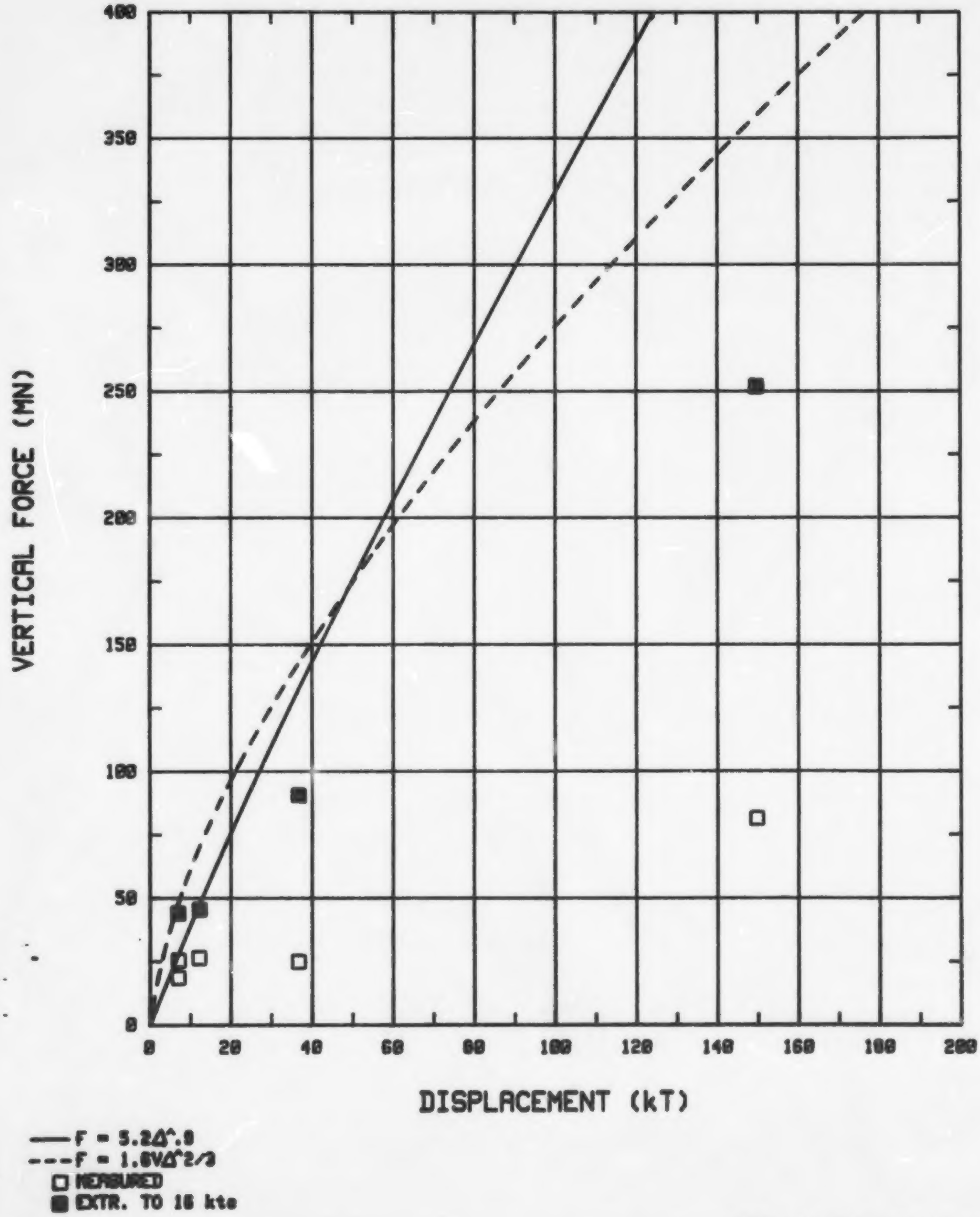

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Figure 5.2.10 plots measured values of vertical force versus displacement along with extrapolated values to 16 kts (linear extrapolation). These points are compared with the two equations.

$$F = 5.2\ D^{.9}$$ (Canmar if $P = D^{2/3}$ assuming a design speed of 8 m/s)

and

$$F = 1.6\ VD^{2/3}$$

where :

F = Force (MN)
V = Velocity (m/s)
D = Displacement (kT)
P = Power (MW)

These two formulae are typical of current proposals for maximum ship/ice impact force and are only meant to be used in conjunction with the highest ice class.

Figure 5.2.11 plots the same data and equations as before, except that the force is given as a percentage of the weight displacement of the ship.

There is a consensus in Canada today that only the highest ice class should have regulations governing hull girder modulus. For lower ice classes, the designer is to choose the modulus based on engineering judgement and, to ensure ship safety, install a hull girder stress monitoring system with bridge display. The M.V. ARCTIC has such a system today.

While it is clear from the evidence that a large ship with open water hull section modulus (i.e. the M.V. ARCTIC) would not be able to withstand a full speed impact with 'infinite' ice, it is felt that 'due caution' of mariners will ensure that ramming speeds are kept low until the master ascertains if the ice is a threat to the ship.

Unfortunately the full scale data limited to only a few ships and to relatively low speeds. To extend the full scale data, both physical model and numerical model techniques have been used. As part of a Joint Research Program Agreement (hereafter JRPA), Canada (Coast Guard, NRC, and Arctec) and Finland (Technical Research Center of Finland, VTT) are working on both parametric physical model tests and a numerical model of ice response to impact.

5.2.6 Information Deficiencies

The deficiencies in relation to ships' structures relate to the loads to which the structure must be designed, and the materials which should be used. The lack of design load data is the most important deficiency, and should be the highest priority. This is reflected in the present high level of research activity in this area.

a) To update plate design methodology it is necessary to establish realistic loading for multi-year ice and to account for the actual strength mechanisms. The designer or regulator must decide on the design condition (i.e., percent of permanent set) and the design life. If the design condition for the plating is to be a permanent set of more than three percent of the frame spacing, then membrane action must be the design behaviour.

   The best currently available plate strength formula is by Ratzlaff and Kennedy. This approach, among others, should be examined as a way of improving design methods. In addition, the effect of aspect ratio, and load reduction due to plastic behaviour is not well understood, especially in thick plates.

b) Framing may also be designed plastically, except that shear is likely to be the critical stress. Some analysis of buckling and tripping has been performed, but has not yet become standardized in the design spiral. Investigations of plastic or buckling response require sophisticated finite element programs such as ANSYS, ABACUS, ADINA or NASTRAN.

   A concerted effort should be made to understand the complete behaviour of framing under ice loads and to standardise the design methods.

c) The hull girder loads which may be encountered by existing or future ships are still uncertain. The information base which is available covers only a few Arctic ships and of those only two, ARCTIC and MANHATTAN, provide data which applies to high L/D ships. This problem may be addressed in a number of ways:

   i) A long term programme of full scale stress measurements on existing Arctic ships will create a data base of information, which will guide the designer, operator and regulator.

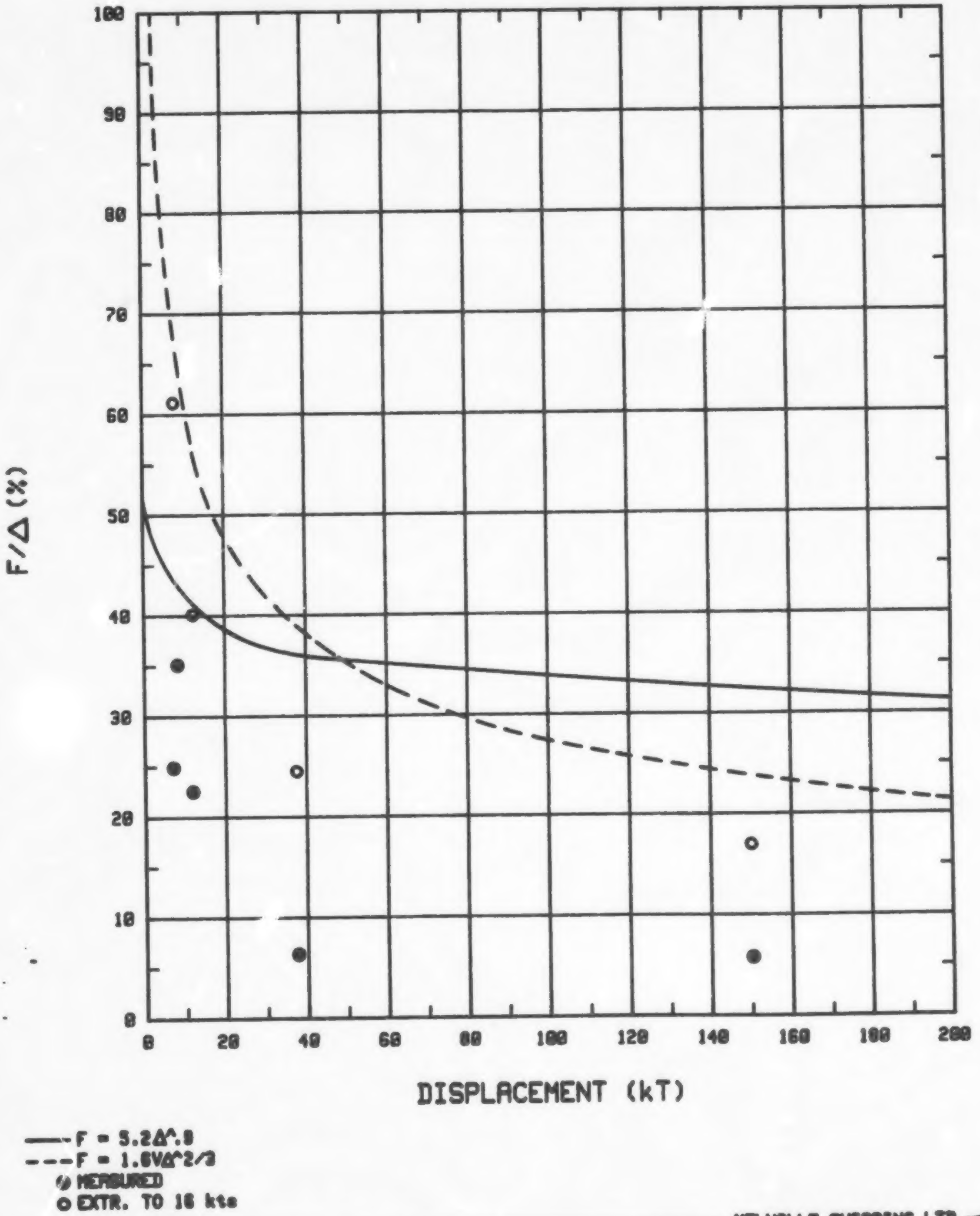
   ii) The numberical modeling of ship/ice interaction during ramming requires an accurate model of ice behaviour. The existing numerical models do not deal effectively with this requirement. The behaviour of ice under load must be investigated to improve the predictive capability of these models. Full scale measurement of ice response to ramming may be the only reliable way to obtain the data.

   iii) The physical modeling of ship/ice interaction during ramming requires the ice to behave similarly at model scale and full scale. The ability to simulate the full scale response of the ice must be developed.

   iv) For numerical models of ship/ice interaction during ramming, the ship's 'added mass' is of great importance. Work is already underway on this problem.

FIGURE 5.2.11

FORCE (%) VERSUS DISPLACEMENT FOR HEAD-ON SHIP/ICE IMPACT



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d) Investigation is required on fracture toughness criteria that are economic to apply. The criteria should incorporate the effects of temperature, stress level, thickness and loading rate.

e) Experimental work is required in which the air and sea temperature is correlated with temperatures in the structure. A two-pronged approach could be used in which results from full scale experimental programmes are used to validate and/or calibrate numerical approaches.

f) The sensitivity of fracture behaviour of steel to strain rate has been noted. Although some data has been gathered, further data is required to establish the spectrum of strain rates experienced by Arctic vessels.

g) The problem of weld corrosion is the subject of current research and this effort should continue. Past research has indicated that the chemical composition can be adjusted to yield favourable properties, but often at the cost of reduced toughness.

5.3 Hull Design and Performance

5.3.1 General

This section deals with the many aspects of hull design and performance. Performance is defined as the ability of a ship to operate in a variety of ice conditions, and the following discussion reviews the background and present understanding of:

- hull form design,
- performance enhancing systems, and
- performance prediction techniques.

Data on the performance of existing icebreaking ships is presented in Section 3, and may be reviewed in association with this section. It will be clear from the following material that information is available from many sources on the performance of ships in level ice, but very little is known or published on performance in other ice conditions.

5.3.2 Hull Form

The hull shape of icebreaking ships is driven by a primary consideration: the lowest power required to make progress in ice. Secondary considerations include: power in open water, manoeuvring and protection of the propeller(s). Fundamental to the selection of a hull form are the following considerations:

- performance in ice of all types
- performance in calm open water
- performance in heavy weather in open water
- manoeuvring capability
- choice of overall dimensions
- ease and cost of construction
- ease of repair, and
- ship type (cargo, icebreaker, etc.)

Optimum shape and efficiency, both in ice and open water, and minimum construction and repair cost are conflicting objectives. The optimum shape in terms of efficiency will likely be complex and therefore expensive and time consuming to build or repair. This only emphasises the importance of optimisation of hull shape, recognising the overall requirements imposed by the vessels operation.

While traditionally shaped icebreakers are still being built, there has recently been constructed a variety of ships with non-traditional shapes. In many cases these designs have been predicated by one particular consideration, such as 'construction cost', 'icebreaking' or 'manoeuvring'. Notwithstanding this, the understanding of hull shape has improved greatly in recent years. The following notes review and comment on the well known 'bow', 'midbody' and 'stern shapes'.

5.3.2.1 Bow Forms

The bow shape of an icebreaker is usually considered to have the four basic design features shown on Figure 5.3.1. Flare angles contribute to the ice 'breaking' and submergence efficiency, waterline angles contribute to the ice 'clearing' efficiency, the stem angle contributes to the 'breaking' and 'submergence' efficiency and is associated with the flare and waterline angles, and forward block coefficient relates to the 'clearing' efficiency and is associated with the flare and waterline angles.

The progression over the last fifteen years has been to increase frame flare, reduce waterline angles, reduce the stem angle and reduce the forward block coefficient, all designed to produce a more efficient icebreaking bow. Many programmes of model testing have been performed to verify these relationships, some are well reported in the literature (Edwards, 1976; Narita, 1981; Noble, 1981) and others are proprietary such as those performed during the Arctic Pilot Project (1978-1982).

However, the selection of bow shape is greatly influenced by the vessel's mission profile, and this is reflected in the shapes which have been adopted over the years. The following review reduces the many variations in shape which have been constructed to several which epitomise the 'concept' or which illustrate the objective(s) of the designer.

a) Straight Stem With Parallel Buttocks

The straight stem, irrespective of stem angle, has been common in Soviet and Finnish icebreakers since the 1950's. Although initially associated with concave buttock lines the form stabilised into the shape illustrated in Figure 5.3.2. The ships which established this bow shape were the MOSKVA class, built in the 1960's, and the URHO class of Baltic icebreakers, built in the 1970's. The MOSKVA class included a forefoot for ice clearing and to prevent beaching during ramming operations. This forefoot was dropped from the later Baltic design but bow propellers were added.

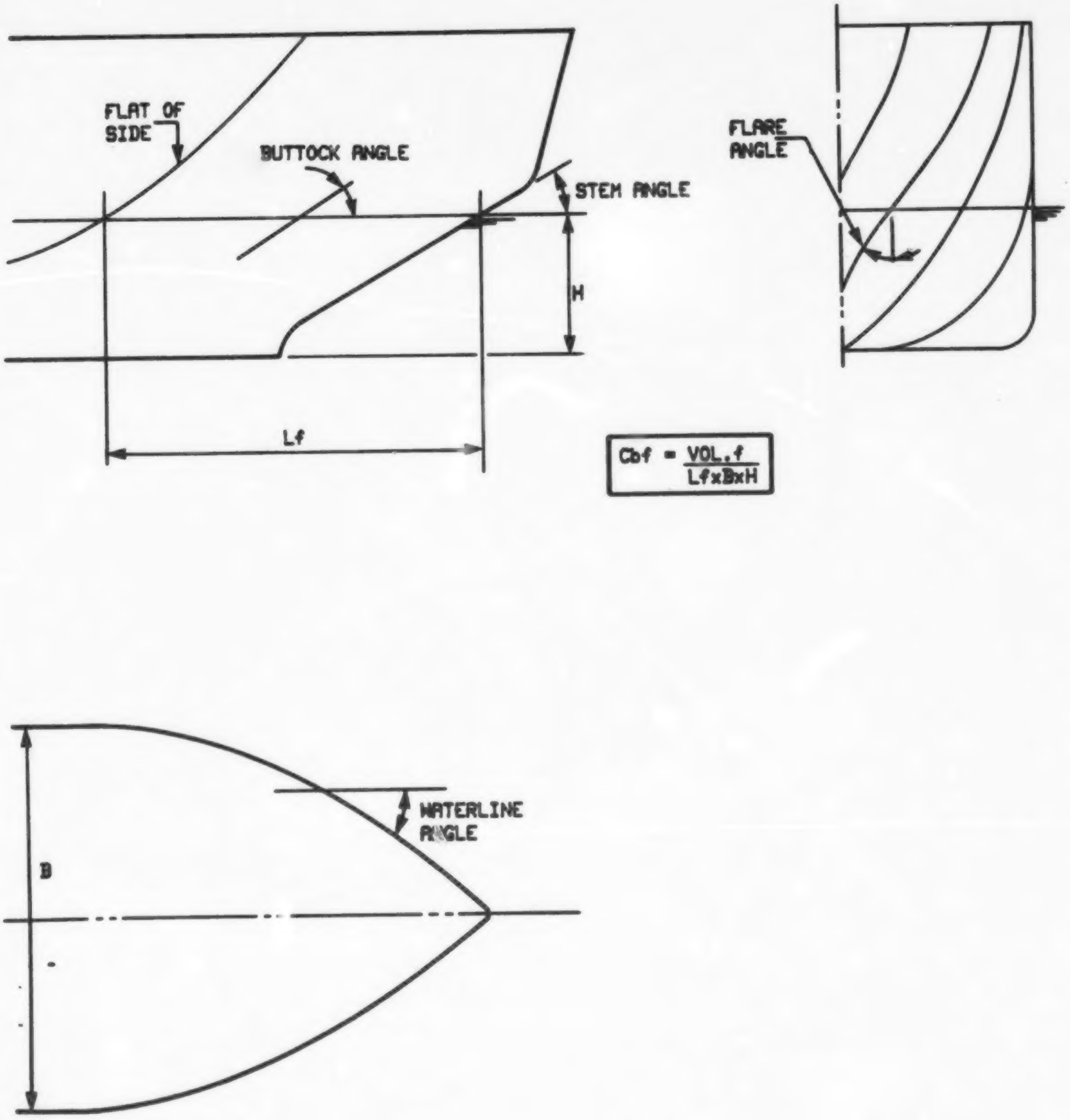
By comparison with earlier icebreakers this shape was finer, with stem angles between 20 - 25°, resulting in generally lower ice clearing resistance. The performance of several ships with this type of bow is shown on Figure 5.3.3.

b) Concave Stem (White Bow)

The concave stem has been used on some of the older icebreakers in association with a variety of buttock, frame and waterline shapes. However, in 1969, Commander R. White of the U.S. Coastguard utilised the concave stem to develop the icebreaking/ice clearing shape illustrated in Figure 5.3.2. The ships which established this shape were the POLAR

FIGURE 5.3.1

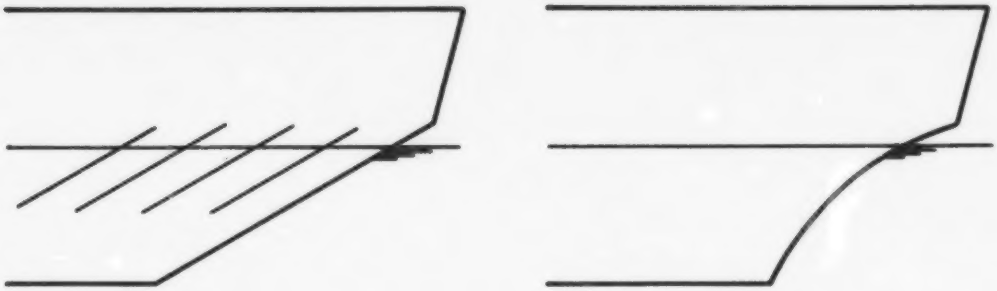
BOW FORM FEATURES


FLAT OF SIDE
BUTTOCK ANGLE
STEM ANGLE
H
Lf
FLARE ANGLE
WATERLINE ANGLE
B

$$\boxed{Cbf = \frac{VOL.f}{Lf \times B \times H}}$$

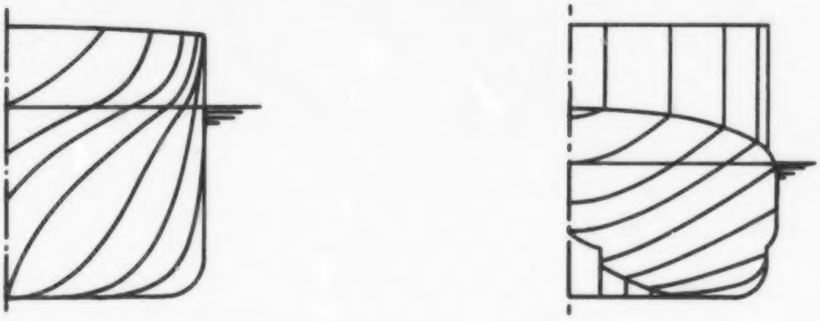
FIGURE 5.3.2

ICEBREAKING BOW SHAPES



STRAIGHT STEM WITH
PARALLEL BUTTOCKS

CONCAVE STEM
(WHITE BOW)

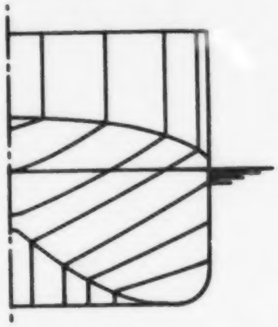


HIGH FRAME FLARE ANGLES
(MELVILLE BOW)

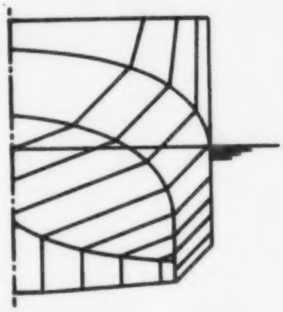
SPOON BOW WITH REAMERS

FIGURE 5.3.2 (cont.)

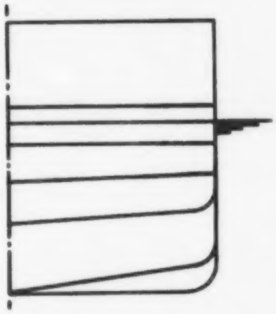
ICEBREAKING BOW SHAPES



SEMI SPOON BOW
WITH CHINES



FLAT FAMILY



THYSSEN WAAS BOW

STAR/SEA, built in the mid 1970's, the ARCTIC, built in the late 1970's, and in a modified form the Canadian R-CLASS, built between 1978 - 1984.

This shape, due to the concave stem, created higher frame flare angles close to the stem, and created a pronounced forefoot which was faired into the hull, allowing the lower waterlines to be extended forward. The performance of several ships with this type of bow is shown on Figure 5.3.3.

c) High Flare Angles (Melville Bow)

High flare angles have not been used in the past except in way of the stem. The combination of flare, waterline and stem angles seems always to have resulted in a distribution of flare angles which does not emphasise their importance. Recent research has shown the importance of the breaking component of resistance, leading to the development of a shape which is particularly directed at reduction of that component. The high frame flare shape is illustrated in Figure 5.3.2. The ship which has demonstrated the value of this shape is the recently modified ARCTIC.

This shape, due to the much higher flare angles throughout the bow length, and when combined with a 20° stem angle and a finer forward block coeficient, offers a large reduction in icebreaking resistance with a complementary decrease in open water resistance. The performance of the ARCTIC with this bow is shown on Figure 5.3.3.

The above bow shapes can be referred to as 'conventional' or 'traditional' in that they represent a progressive improvement in icebreaking resistance while retaining the smooth hull which offers the least resistance in open water. Advances with this form of icebreaking bow have, lead to an increase in performance for the ARCTIC after the recent conversion from a 'White' to a 'Melville' bow.

d) Spoon Bow With Reamers

The spoon shaped icebreaking bow offers advantageous and constant frame flare throughout the bow length, resulting in more efficient icebreaking. This shape has been used in the past, but use was discontinued due to the high resistance in heavily snow covered ice caused by the very flat frame flare. Since the introduction of air bubbler systems, snow resistance is now of less concern and a modification of this shape has been re-introduced on the CANMAR KIGORIAK, built in 1979, and the ROBERT LEMEUR, built in 1981. An illustration of the shape is shown on Figure 5.3.2.

These vessels have used a spoon bow with an extended beam at the shoulder (reamer), high flare angles, low stem angles and circular or oval waterlines. The extended beam was introduced for two reasons: to reduce the resistance of the midbody section of the ship, and to increase the manoeuvring capability. The design has demonstrated good icebreaking performance, but the extended beam with the abrupt change in shape at the shoulder has a detrimental effect on open water resistance. The performance of the two ships with this type of bow is shown on Figure 5.3.3.

e) Semi Spoon Bow With Chines

The semi spoon bow with chines is an adaptation of the previous bow type, replacing the extended beam with a shoulder chine, reducing the flare angles and incorporating a larger ice clearing wedge. An illustration of the shape is shown on Figure 5.3.2. The ships which have used this design are the Beudril vessels TERRY FOX, KALVIK, IKULUK, and MISCAROO, all built in 1983 for ice management operations in the Beaufort Sea.

The reduced frame flare angles close to the shoulder will improve the icebreaking resistance, but the large ice clearing wedge, which may be effective in preventing ice from entering the propeller disc, will add to the ice clearing resistance. The design has demonstrated an improved icebreaking performance, but the shoulder and wedge chines will have a detrimental effect on the open water resistance. The performance of the two ship classes with this type of bow is shown on Figure 5.3.3.

f) Flat Family

The flat family of bow shapes replaces the spoon shape and the semi spoon/chine bow with flat plates. The intention is to retain, to the extent possible, the icebreaking capability of that bow but to reduce the construction cost. An illustration of the shape is shown on Figure 5.3.2. The ships which have used this shape include the ARCTIC NANABUSH, built in 1984, and the ARCTIC IVIK, built in 1985.

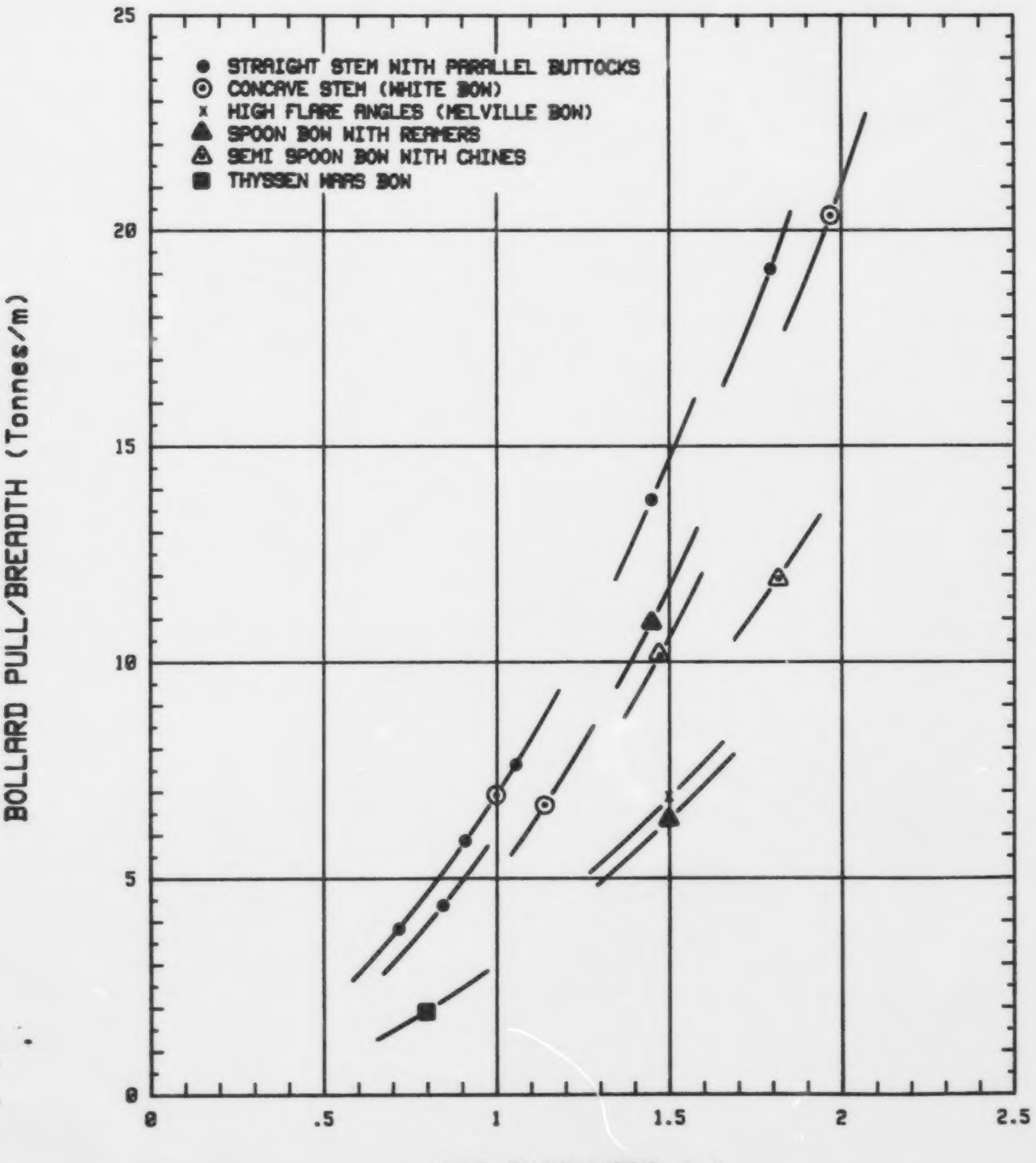
This bow shape is a compromise between the need for an acceptable icebreaking capability and construction cost. The design has demonstrated an acceptable level of icebreaking capability, but the shoulder and wedge chines will have a detrimental effect on open water resistance.

g) Thyssen-Waas Bow

The Thyssen-Waas bow is an icebreaking concept which breaks the ice first by shearing at the maximum beam of the ship and then breaking in bending across the front of the bow. The principal features of the shape are a transverse flat waterline at the extreme forward end, extended beam at the

FIGURE 5.3.3

ICEBREAKING PERFORMANCE OF SEVERAL HULL SHAPES



Bollard pull is measured or calculated
Data is adjusted for a 2 knot ship speed

extreme forward end, a very low stem angle with an ice clearing forefoot, and high flare angles below the waterline. An illustration of the design is shown on Figure 5.3.2. An early Thyssen-Waas design was constructed and installed on the existing MAX WALDECK in 1980.

The design reduces the icebreaking resistance by greatly reducing the breaking component of resistance. The predominent mode of ice failure with this design is shearing, rather than bending (which is predominent with most other icebreakers). In this the design succeeds very well, although the resistance in open water is high and questions remain on the designs behavior in extremely rough ice and in rough sea. The performance of the MAX WALDECK with this type of bow is shown on Figure 5.3.3.

Bow shapes (d) thru (g) can be referred to as 'unconventional' or 'non-traditional', in that they are a distinct departure from the smooth hull shapes. There appear to be benefits and drawbacks with these shapes, leading to the conclusion that bow shape selection must be based on a full understanding of the ship's operational requirements.

It would appear from Figure 5.3.3 that the the best of the traditional shapes has performed as well in level ice as the best of the non-traditional. If open water efficiency is considered to be important for a particular ship then the balance would appear be in favour of an advanced but traditional bow shape.

5.3.2.2 Midbody Forms

The selection of midbody shape has, in the past, almost without exception, dealt only with three parameters: flare angle, parallel midbody and longitudinal taper. This is reflected in the shapes which have been adopted over the years. The following review reduces the many variations which have been constructed to several which epitomise the 'concept' or illustrate the objective(s) of the designer.

a) Frame Flare

The principle objective of midbody flare is to reduce the resistance when the midbody passes through the channel broken by the bow or when the shoulder must break ice. The WIND class icebreakers had a flare angle at midships of 20°, the MOSKVA class an angle of 15.6°, the POLAR class an angle of 12.5°, and the R-class an angle of 4.5°. Initially, these flare angles were associated with a circular midship section shape but, more recently, some 'flat of side' has been introduced, a principle which has been supported by several series of model tests (Kashteljan, 1984, Arctic Pilot Project, 1978-82).

The Beaufort Sea ice management vessels have vertical sides in way of the midbody. Although the design was selected primarily to reduce the construction cost, the move was made only after designing the bow shape to reduce or eliminate midbody resistance. The CANMAR KIGORIAK and ROBERT LEMEUR have reamers at the forward shoulder to widen the channel, eliminating midbody resistance, and the TERRY FOX, MISCAROO and ARCTIC IVIK classes have a shoulder knuckle with high flare angles forward of the knuckle to break a channel wider than the ship.

Icebreaking cargo ships tend to have a long parallel midbody. Some of these vessels, despite the high construction cost, have introduced midbody flare (LUNNI and KIISLA). Others, for example the ARCTIC or S.A.15 class, have opted for vertical sides in way of the parallel midbody. Some designs have been considered, although not built, which create flare at the waterline but change to the vertical at a knuckle below the waterline.

b) Parallel Midbody

Until recently, icebreakers had no parallel midbody. The hull shape at and below the waterline changed immediately forward and aft of midships. This shape was based largely on the belief that parallel midbody would expose the icebreaker to higher resistance when moving astern during ramming and in ice which is under pressure. However, the lack of parallel midbody locates the shoulder, or the point of maximum beam, too far aft, resulting in lines which are not conducent to efficient icebreaking.

To improve the icebreaking efficiency it has been suggested that the forward shoulder of the icebreaking waterline should be as far forward as possible (Schwarz 1985). This would result in a parallel midbody section but, due to the higher frame flare angles which are created, a wider channel is broken allowing the parallel midbody section to pass with little or no resistance.

This concept has been demonstrated on the Beaufort Sea ice management vessels, which all have flat sides, and on all of the icebreaking cargo ships which must unavoidably have long parallel midbody sections. However, this is a problem of optimisation, requiring a balance between ice 'breaking' and 'clearing' resistance.

c) Longitudinal Taper

Longitudinal taper, in way of the icebreaking waterline and below, is intended to eliminate any ice resistance aft of the forward shoulder. Several barges have been built with this hull shape, and have operated successfully for several years. These barges, the ARCTIC BREAKER class, are pushed by relatively small tugs which operate in the sheltered water behind the barge.

This shape, combined with an efficient bow form, offers the same benefits as a reamer bow with a vertical midbody section. The drawbacks are an exposure to becoming stuck in pressured ice, and a higher construction cost. No icebreakers or icebreaking cargo ships have used this concept.

The midbody shape of icebreaking cargo ships is governed largly by the vessels length, but also by the need to minimise construction costs. While some vessels do have midbody flare most have vertical sides. By contrast, icebreaker operators are more concerned with the ships ability to maneouvre than with construction cost or with resistance. For this reason it is likely that pure icebreakers will retain the concept of limited parallel midbody, while improving the icebreaking efficiency by appropriate design of the shoulder shape.

5.3.2.3 Stern Forms

The selection of a stern shape has in the past been governed primarily by the number of stern propellers. More recently, the objective of protecting the propeller from ice interaction has generated a number of new stern shape concepts. The following review illustrates the stern shapes which are now in use.

a) Conventional Stern(s)

Most icebreakers are equipped with two or three open fixed pitch propellers. The MOSKVA, SOROKIN and POLAR classes typify the triple screw stern arrangement, and the URHO and CHECHKIN classes typify the twin screw arrangement.

The triple screw stern arrangement comprises a centre propeller and rudder supported in a conventional sternframe, with another propeller port and starboard supported in large bossings. The twin screw arrangement uses similar bossings with rudders astern of both propellers. These two arrangement rely on the ice clearing capability of the bow to move the broken ice away from the ship, thereby limiting ice interaction with the propellers.

Since the late 1970's, shrouded propellers have been introduced on several vessels. Primarily utilised to augment the thrust which can be obtained at low ship speed, the nozzle also offers some protection to the propeller. These nozzles are supported in a conventional sternframe, as on the CANMAR KIGORIAK, or from the aft end of twin screw skegs, as on the ROBERT LEMUER and MISCAROO, or from the stern shell structure as on the POLARSTERN.

b) Semi Ice Clearing Stern

The semi ice clearing stern is characterised by long shallow upward sloping buttock lines at the stern. The objective is to allow the broken ice pieces to move upward to the surface well ahead of the propeller(s), thereby limiting any ice interaction. The Beaufort Sea ice management vessels characterise this feature, although ice interaction with the propeller has not been eliminated, perhaps due to the very deep ridges which those vessels must transit.

c) Ice Clearing Island

The ice clearing island was introduced on the ROBERT LEMEUR. The island comprises a wedge protruding below the ship's hull from the baseline forward of the propeller, sloping upwards to the waterline aft of the propeller. The objective is to guide ice pieces away from the propellers.

All icebreakers are designed to move astern in ice. Some may only operate in that mode in a broken channel or in broken ice, others such as those which perform a support role must break ice while moving astern. Depending on the mission profile, these ships are designed either with an ice breaking/defecting shape and/or with an ice horn(s) which prevent oblique loads on the rudder(s) when in the midships position.

From experience gained in the Beaufort Sea it is apparent that despite the innovative stern designs there is still substantial propeller/ice interaction, leading again to the conclusion that the overall design must be chosen after considering all aspects of the selection process.

5.3.3 Performance Enhancing Systems

Until the mid 1970's icebreakers used heeling systems and/or bow propellers to reduce the drag forces acting on the ship during ramming operations. The motion of the ship when the heeling system is operating, or the turbulence created by the bow propellers, helped to lubricate the hull/ice interface and hence reduce the friction forces. These systems are still options, although bow propellers are no longer installed on icebreakers. Generally, these two systems have been replaced by the use of 'low friction coatings' or a combination of these coatings and one of several hull lubrication systems.

The systems which are presently installed are:

- the 'Air Bubbler System', installed on many vessels including the LUNNI class, ARCTIC, and the S.A.15s

- the 'Air Bubbler/Water Injection System', installed on the POLARSTERN, and

- the 'Water wash System', installed on the CANMAR KIGORIAK and ROBERT LEMEUR

Very little information is available on the performance of ships when fitted with these means of reducing hull/ice friction. The data which is available is discussed in the following notes.

5.3.3.1 Low Friction Coatings

The drag forces, due to friction between the ship's hull and the ice, have long been recognised to contribute a large percentage of the total resistance to motion (Vance, 1975). The friction factor most often considered when assessing icebreaking resistance is 'kinetic'. which is substantially lower than 'static' friction and does increase with hull roughness. The influence of friction on resistance has been demonstrated during model tests and during full scale trials (Makinen, 1975; Calabrese, 1978).

The use of low friction/high adhesion coatings was proposed as a means of reducing these drag forces. Many experiments were performed (Calabrese, 1974-1980) to identify coatings which would accomplish the low friction objectives yet still have sufficient abrasion and impact resistance for use on an icebreaker.

Two coatings emerged from this early work, Inerta 160 and Zebron. Both coatings had the necessary qualities although Zebron appeared able to achieve lower coefficients of friction (Calabrese, 1980). Perhaps due to the better bond strength exhibited by the Inerta 160 coating, this has become the more widely used material and is now installed on several hundred vessels.

5.3.3.2 Air Bubbler System

The Wartsila air bubbler system was introduced on Baltic icebreaking vessels in the 1970's. The declared objective was to decrease the ice resistance in various ice conditions and reduce the risk of becoming stuck (Makinen, 1977). These systems were comprised of one or more air compressors which force air through a system of pipes to nozzles at the ship's side below the waterline. The air, when forced from the nozzles, bubbles to the surface taking entrained water with the bubbles and lubricating the interface between the ice and the ship's hull.

The early evidence indicated a decrease in resistance throughout the speed range. Later trials, on the ARCTIC, appear to indicate that the benefits may lie only in the low speed range. Nevertheless, many ships are now being built with air bubbler systems. The anciliary benefits of this system may be the most important. They include:

- use of the system to lubricate the hull during the ramming process, while in pressured ice, or in sticky ice conditions.

- use of the system as a maneouvring aid.

It has been suggested that the power which is used for the air compressors could more effectively be installed in the main propulsion system. While this may be true under some circumstances, such as thick level ice without snow cover, in most cases the conditions will be more like those in which the system will show a benefit.

5.3.3.3 Air Bubbler/Water Injection System

The air bubbler/water injection system has recently been installed on the POLARSTERN. In this system, air is injected into water being pumped to nozzles at the ship's side. Very little information is available on the efficiency of the system; trials which were conducted in the Labrador Sea in 1984 were inconclusive as the water melts for the system became easily clogged by ice leaving the system inoperative.

5.3.3.4 Waterwash System

The waterwash system installed on the CANMAR KIGORIAK and ROBERT LEMEUR pumps a large volume of water to nozzles at the ship's side at the bow above the waterline. The objective is to flood the ice with water, lubricate the interface between the ice and the ship's hull, and reduce the resistance. On the ROBERT LEMEUR the system has achieved a 20% to 30% reduction in resistance over the whole range of speed (Churcher, 1984a).

This system may offer a greater reduction in resistance than can be achieved with the air bubbler system. However, the benefits which are achieved with the air bubbler system when moving astern or when maneouvring may be of more importance than a reduction in pure icebreaking resistance.

5.3.4 Performance Prediction Techniques

The major problem associated with the prediction of performance for an ice transitting ship is the variability of the environment in which it may operate. In the case of the Canadian Arctic this large variability has been discussed in the environment section of this report and may include any combination of level ice, rubbled and rafted ice, pressured ice or pack ice.

As a result of this variability the performance prediction of icebreakers is usually confined to specific ice regimes, characterised with 'average' or 'typical' values. The most common ice regime used for this purpose is level ice. Ridges and rubble fields are also used although they are considerably more difficult to characterize in a consistent fashion.

There are two procedures commonly used to predict the performance of an icebreaking ship, Semi-Empirical and Analytical.

The Semi-Empirical method, as its name suggests, uses experiments to evaluate the performance of a particular hull form. The experiments may be either at model or full scale and the analysis involves some rationalisation of the variables that affect the performance of the ship or model in ice. This procedure was first introduced to ice experiments in the 1960's (Kashletjan, 1968).

The Analytical method uses a mathematical representation of the energy or kinematics of icebreaking to derive formulations that 'model' the ship response to the action of ice. Early analytical models include Enkvist (Enkvist, 1972), Milano (Milano, 1973), Naegle (Naegle, 1980) and most recently Carter (Carter, 1983).

There are a number of ways in which the performance of an icebreaking ship may be graphically represented for prediction or comparison purposes. The most common is associated with level ice performance and plots the bare hull resistance against hull speed for a range of ice thicknesses together with the maximum thrust capability of the ship (reduced by the thrust deduction). An example of this type of presentation is shown on Figure 5.3.4 Another form of this representation is to replace the resistance with required thrust or power.

It is common for more than one of these procedures to be used and, as a result, designers should be familiar with their assumptions, limitations and reliability. The following sections present a review of each of the following performance prediction techniques:

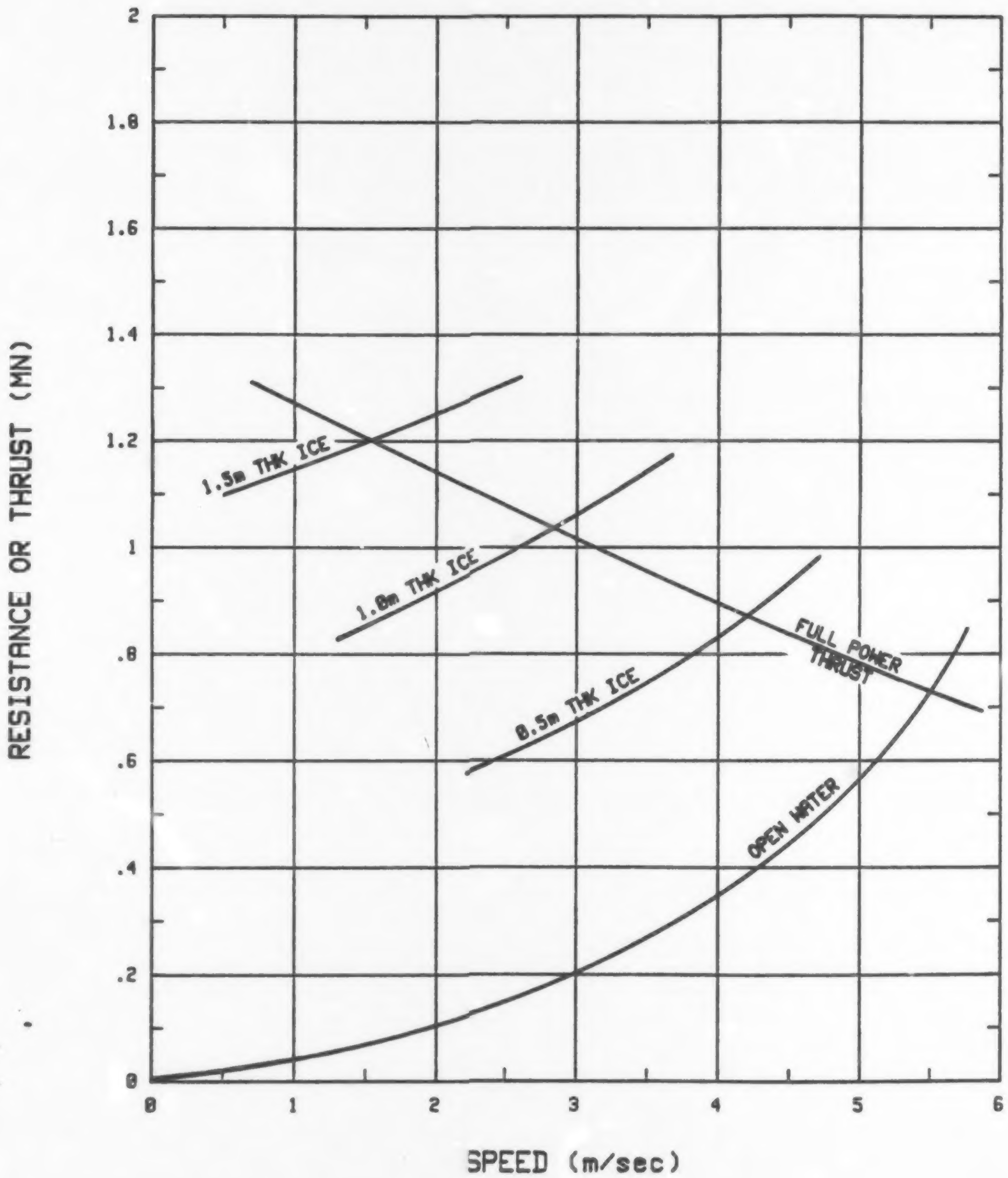
- Model scale tests
- Analytical and semi-empirical analysis
- Empirical analysis

5.3.4.1 Model Scale Tests

The ice model basins which are presently operating are shown on Table 5.3.1. The objective of model tests is to evaluate the full scale performance of an icebreaker by observations and measurements taken at model scale. To accomplish this it is necessary to simulate the prototype (full scale) condition, in all respects, at model scale.

FIGURE 5.3.4

PERFORMANCE ASSESMENT



ICE STRENGTH = 500 kPa

The scaling relationships presently used by ice tanks have been well documented (at least 4 authors) and may be summarised as:

Froude Number - Linear Dimensions, speed
Cauchy Number - Elasticity
Reynolds Number - Viscosity
Ice Number - Fracture toughness

The Froude number is universally adopted as the main scale relationship and requires the linear dimension of the prototype ship to be scaled using a constant scale factor ( ). The Cauchy number is associated with the elasticity of the ice, the Reynolds number with viscosity, and the ice number with fracture toughness, which has only very recently been investigated.

The prototype ship, scaled using Froude scaling, can be tested under two conditions, resistance and self-propulsion. The resistance tests involve pulling the bare hull through the ice. The model will be restrained in surge, yaw and sway, but free in all other respects. During these experiments it is very important to have a rigid connection between the model and carriage. This will result in high frequency data output that may be filtered without affecting the significantly lower frequency icebreaking frequencies which make up the model resistance.

There are a number of different procedures used in model tanks to improve the scaling capability of model ice. These range from modifying the crystaline structure of the naturally frozen model ice, to simulation with paraffin based waxes that do not require a freezing environment. The most widely used procedure is to modify the crystaline structure of natural ice by using dopants and specialised freezing techniques (Timco, 1979; Baker, 1985). The most recent of these dopants is EG/AD/S ice (Timco, 1985) in Canada by the National Research Council.

Simulated ice covers are usually based on parrafin wax type compounds with plastic globules suspended in the mix. They are only used in one or two ice tanks in the world and generally are not appropriate for modelling ship/ice interaction.

The ice characteristics that are considered important in model icebreaking thickness are; flexural strength, crushing strength, shear strength, elastic modulus, fracture toughness and friction. The procedures used to measure these values have been discussed in the published literature.

The most important are ice thickness and flexural strength. With very few exceptions these are the two main parameters used by model tanks to characterise an ice sheet. Usually both ice thickness and flexural strength are scaled using the Froude scale ratio ( ) and in modern ice tank the thickness can be reproduced to within about 1.0% of the thickness and the flexural strength to within about 5-10% of the strength.

TABLE 5.3.1

ICE BASINS OF THE WORLD

YEAR	COUNTRY	CITY	FACILITY OPERATOR	TYPE OF DOPANT	BASIN DIMENSIONS		
					LENGTH (m)	WIDTH (m)	DEPTH (m)
1955	U.S.S.R.	Leningrad	Arctic and Antarctic Research Inst.	Salt (3%)	13.50	1.90	1.70
1969	Finland	Helsinki	Wartsila Shipyard	Salt (2%)	39.00	4.80	1.20
1970	Canada	Calgary	Esso Resources	Salt (Var)	54.90	30.50	3.00
1971	W. Germany	Hamburg	H.S.V.A.	Carb (1%)	37.00	6.00	1.50
1974	U.S.A.	Columbia	Arctec Incorporated	Salt (.4%)*	30.50	3.70	1.50
1977	Canada	Kanata	Arctec Canada Ltd.	Carb (.5%)*	30.50	4.90	1.50
1979	U.S.A.	Hanover	C.R.R.E.L.	Carbamide	36.60	9.20	2.50
1981	Canada	Ottawa	N.R.C. Hydrau. Lab	Carbamide	19.00	7.00	1.20
1981	Japan	Tokyo	Japan Ship Res. Inst.	Carb/Salt	35.00	6.00	1.80
1981	Canada	Calgary	Arctec Canada Ltd.	Modice	30.5	7.3	1.4
1982	Japan	Nippon Kokan	Carbamide	Carbamide	20.00	6.00	1.50
1983	Finland	Helsinki	Wartsila Shipyard	Salt (2%)	77.30	6.50	2.30
1984	W. Germany	Hamburg	H.S.V.A.	Carb (1%)	78.00	10.00	2.50
1985	Canada	St. John	N.R.C. (IMD)	EG/AD/S	90.00	12.00	3.00

* Tanks now also using modice.

The scaling relationships presently used by ice tanks have been well documented (at least 4 authors) and may be summarised as:

Froude Number - Linear Dimensions, speed
Cauchy Number - Elasticity
Reynolds Number - Viscosity
Ice Number - Fracture toughness

The Froude number is universally adopted as the main scale relationship and requires the linear dimension of the prototype ship to be scaled using a constant scale factor ( ). The Cauchy number is associated with the elasticity of the ice, the Reynolds number with viscosity, and the ice number with fracture toughness, which has only very recently been investigated.

The prototype ship, scaled using Froude scaling, can be tested under two conditions, resistance and self-propulsion. The resistance tests involve pulling the bare hull through the ice. The model will be restrained in surge, yaw and sway, but free in all other respects. During these experiments it is very important to have a rigid connection between the model and carriage. This will result in high frequency data output that may be filtered without affecting the significantly lower frequency icebreaking frequencies which make up the model resistance.

There are a number of different procedures used in model tanks to improve the scaling capability of model ice. These range from modifying the crystaline structure of the naturally frozen model ice, to simulation with paraffin based waxes that do not require a freezing environment. The most widely used procedure is to modify the crystaline structure of natural ice by using dopants and specialised freezing techniques (Timco, 1979; Baker, 1985). The most recent of these dopants is EG/AD/S ice (Timco, 1985) in Canada by the National Research Council.

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The most important are ice thickness and flexural strength. With very few exceptions these are the two main parameters used by model tanks to characterise an ice sheet. Usually both ice thickness and flexural strength are scaled using the Froude scale ratio ( ) and in modern ice tank the thickness can be reproduced to within about 1.0% of the thickness and the flexural strength to within about 5-10% of the strength.

The remaining ice characteristics are not scaled as consistantly and it is important to recognise the effect this may have on the results obtained from the model experiment (Baker, 1985).

Crushing strength is generally too low at model scale when the appropriate flexural strength is scaled correctly. As a result, care must be taken when model testing a bow that tends to crush ice excessively since its performance will be overestimated. The crushing strength of natural ice is strain dependent so there is some possibility of optimising the model scale to suit the strain rate, however, this is not always possible or practical (Timco, 1979).

The shear strength of model ice has not been investigated in detail, however from the little work that has been done it is considered to be representative of full scale.

The elasticity of the model ice is usually represented as a ratio of the elastic modulus and flexural strength (E/σ). In full scale this ratio is believed to be about 3,000 - 4,000 at model scale, it ranges from about 900 - 1,200 but may drop as low as 200.

The implication of this on the model test may be significant (Schwarz, 1977). As the ice becomes more elastic it will absorb more energy during its breaking process than will full scale ice. This is clearly visible during the ice test as a 'rubbery' appearance of the ice sheet and the lack of well defined cracks forming around the bow of the icebreaker. The importance of fracture toughness was identified in ice model testing some years ago, however it is only recently being investigated in any detail. The fracture toughness of the ice gives an indication of how well the model ice duplicates the mechanics of cracking and the ice toughness. This area of research represents a very new development and may result in a new approach to ice model testing using a new non-dimensional group for scaling the model speed instead of the conventional Froude scaling.

The friction coefficient has been recognised as a major problem in model ice testing for many years. Conventional Froude scaling, which assumes Coulomb type friction between the ice and hull, requires the (non dimensional) friction coefficient to be identical between prototype and scaled model. Recent work on full scale vessels instrumented to measure friction (Hoffman, 1986; Enkvist, 1986) and sample testing of model and natural ice (Forland, 1985) indicate that the friction phenomenon is not Coulomb but dependent on normal force, relative motion, surface configuration (material sliding on ice or ice sliding on material) and roughness. Research is currently in progress to investigate the influence of this phenomenon.

Although level ice is the most common ice regime duplicated at model scale and the most consistent, it is also possible to duplicate a number of other regimes and operating conditions. Table 5.3.2 lists a number of these alternatives together with problems associated with them.

5.3.4.2 Analytical and Semi-empirical Models

a) Level Ice

Early attempts to formulate the ice resistance problem date back to Runeberg (1888), who analyzed the forces and friction at the stem of an icebreaker. This attempt was followed by slow progress until Kashteljan (1968) proposed the first rational breakdown of the ice resistance into components based on functional mechanisms of icebreaking. These mechanisms include breaking, submersion (or gravity) and speed related (inertial) effects.

Since Kashteljan's work, several studies have followed, and many models have been proposed for the prediction of level ice resistance and the evaluation of concepts in the initial stages of ship design. Published review of such models have been performed earlier by Edwards (1978) and Nawwar (1979). These reviews have also been updated in 1983.

Table 5.3.3 provides a summary of analytical and semi-empirical level ice resistance models. Many of the empirical models have been excluded from this summary for two reasons:

- Their empiricity limits their applicability or generalization to other hull forms;

- there are many of these models; virtually for every full scale trial or ship model test there is an empirical equation that best fits the data. Therefore, in the context of a general prediction capability, such empirical models have limited value without further analysis or manipulation.

This table provides an overview of the type of data used in developing the model, and the number of terms used in each, with the exception of computer coded models which are usually too complex to be described by a single equation. The table also lists the country of origin where the model has been developed.

The level ice resistance models often assume a certain breaking pattern of the ice at the stern and along the hull.

The assumed patterns determine the process of failure and hence can be used to estimate the relevant ice loads. Generally the breaking patterns proposed can be divided into two different models, as illustrated in Figure 5.3.5.

- **Wedge pattern** - Lewis (1970), Milano (1973) and Carter (1983), among others, suggest that radial cracks extend outward from the stem and divide the ice sheet into wedges which then fail in bending. This cracking pattern is more characteristic to ramming or impact operation.

TABLE 5.3.2

ICE REGIMES AND OPERATING CONDITIONS SIMULATED IN THE ICE MODEL TANK

SIMULATION	COMMENTS
A. Continuous Progress	
. Unconsolidated Pack	- Simulated by breaking up a level ice sheet. Major problem is duplicating similar conditions for a series of tests and the rapid decay of the model ice.
. Broken Channel	- Easily simulated using the broken track after the level ice tests.
. Manoeuvring	- May be tested in the form of a channel breakout back and full or turning circle. However the test requires a large tank. Very little work has been done in this area.
B. Ramming	
. Level Ice	- The most consistent form of ramming analysis at model scale. However many test rams are required to build up a data base due to the scatter of results.
. Rubble Fields	- Simulated by compressing, and possibly refreezing a level ice sheet. The tests are very difficult to duplicate consistently.
. Ridges	- Built by either compressing a broken level ice sheet into a mould and refreezing or from blocks of the level ice sheet, built by hand. The tests are difficult to duplicate consistently and presents difficult data interpretation problems.

Cusp pattern - The other model contains two types of failure: local failure near the bow by crushing and shearing; and local crushing and finally bending of the ice by the hull sides near the bow. Bending of the ice sheet by the hull causes failure by concentric cracks. The ice broken off is in the shape of half moons or cusps, broken off in rows. The number of rows of cusps being broken on each side of the ship depends on ice thickness, ship speed and ship beam.

This pattern is more characteristic of continuous operation. The local crushing and cusp failure pattern is supported by Kashteljan (1968), Enkvist (1972), Milano (1973) and Naegle (1980) among others. Most recent observations by Kotras (1986) on the Polar Class icebreakers support earlier observations and models for cusp proportions and size, as used in the development of comprehensive resistance prediction computer models such as SPLICE, developed for the USCG, and RICE for Transport Canada.

The resistance of a ship in ice is generated by several mechanical processes, broken down into a number of components and summed to give the total resistance. Usually at least two components are used and sometimes as many as five or seven are described (refer to Table 5.3.3).

The two most frequently used components are:

R_σ - resistance from bending and breaking the ice sheet. This is 10 to 60% of the total icebreaking resistance according to Enkvist (1985). This term is dependent on ice flexural strength and thickness.

R_v - speed dependent resistance which arises from the momentum interchange between the ice pieces and the ship. This component is a function of ice thickness, ship velocity and hull form.

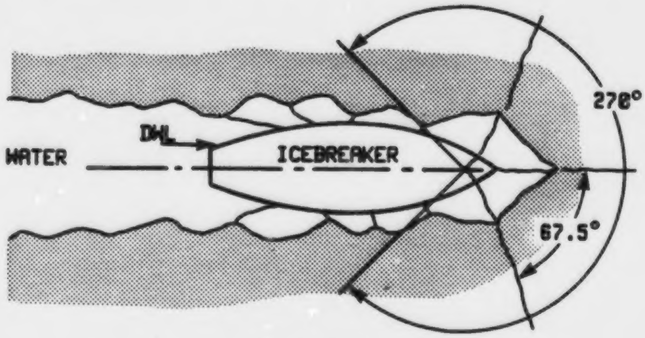
A third component which is used in many prediction formulas, for instance, Kashteljan (1968), Lewis (1970), Enkvist (1972), Naegle (1980), Vance (1975), among others, is an inertial term, R , to describe the force required to upend and turn the broken floes as they are forced under the ship. In some analytical theories this term also includes a gravitational term to describe the buoyancy forces that ventilated floes exert on ships. As the floe is being upended, water from beneath the floe does not have time to flood the downward moving surface of the floe and a ventilated space is created between the floe and the ship. Thus a static head is created under the floe.

The friction between the ice and the hull seems to be the resistance component which is least understood. Many empirical formulae ignore friction altogether and account for it in the empirical constants e.g. Lewis (1982) and Kashteljan (1986). Usually friction is included in the submergence resistance since, as the floes are submerged and moved down

FIGURE 5.3.5

BASIC PATTERNS OF ICE BREAKING

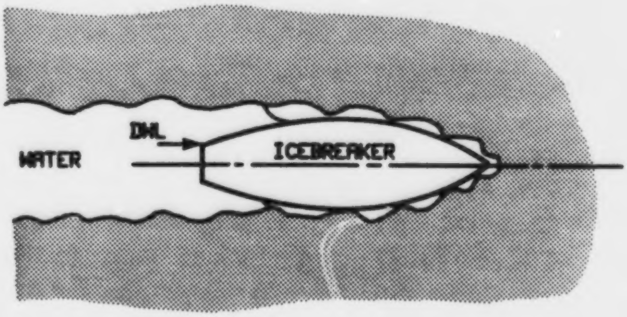
A. WEDGE PATTERN



270°
DWL
WATER
ICEBREAKER
67.5°

RAMMING

B. CUSP PATTERN



DWL
WATER
ICEBREAKER

CONTINUOUS

MELVILLE SHIPPING LTD

TABLE 5.3.3

SUMMARY OF ANALYTICAL AND SEMI-EMPIRICAL LEVEL ICE RESISTANCE MODELS

	Kashteljan, et al (1968)	Edwards, et al (1976)	Major-POLAR VII (1976)	Major-LOUIS S. (1976)	Lewis & Benze (1971)	Edwards et al (1973)	Nawwar & Edwards (1978)	HSVA (1976)	Enkvist (1972)	Kotras et al (1974)	Johansson & Makinen (1972)	Lewis & Edwards (1970)
Type of Data	B	M	M	M	M	M	M	M	M	M	-	F
No. of Terms	3	4	5	2	3	3	3	3	4	4	3	3
R_σ : σBh	X	X	X		X	X	X		X	X	X	
σh^2								X				X
R_s : γBh^2	X	X	X	X	X	X	X	X	X	X	X	X
γBhT									X		X	
γLh^2										X		
γBhL												
R_v : γBhv							X					
$\gamma Bh^{1.5}v\sqrt{g}$		X	X		X	X		X				
$\gamma Bhv^2/g$		X	X						X	X	X	X
$\gamma B^{1.65}hv$	X											
$\gamma LB^{.25}h^{.65}v/\sqrt{g}$												
$\gamma B^{1.5}hv/\sqrt{g}$												
$\gamma LB^{.5}h^{.5}v/g$												
Other Combination terms			X	X	X							
COUNTRY	R	C	C	C	A	C	C	G	F	A	F	A

	Edwards et al (1972)	Edwards et al (1972)	Kloppenburg (1975)	Edwards et al (1976)	Edwards et al (1976)	Vance (1975)	Lewis et al (1982)	Wartsila (1972-1975)	Lewis et al (1982)	Runburg (1888)	Milano (1972)	Naegle (1980)
Type of Data	M	F	M	M	F	M	F	M	F	-	-	-
No. of Terms	3	3	5	3	3	3	3	3	7	2	*	*
R_σ : σBh	X			X	X	X	X					
σh^2			X									
R_s : γBh^2	X	X	X	X	X	X	X					
γBhT			X									
γLh^2												
γBhL												
R_v : γBhv												
$\gamma Bh^{1.5}v\sqrt{g}$	X	X		X	X							
$\gamma Bhv^2/g$		X	X									
$\gamma B^{1.65}hv$												
$\gamma LB^{.25}h^{.65}v/\sqrt{g}$						X						
$\gamma B^{1.5}hv/\sqrt{g}$			X									
$\gamma LB^{.5}h^{.5}v/g$							X					
Other Combination terms								X	X			
COUNTRY	A	A	G	C	C	A	C/A	F	C/A	UK	A	A

	Baird & Kotras (1982)	Enkvist (1972)	Pozniak & Ionov (1981)	Makinen & Ross (1973)	Vance (1980)	Mueller & Ettema (1984)	Mathews (1984)	Carter (1983) Analytical	Tatinclaux (1984) Emp.(Jan)	Tatinclaux (Apr.1984)Emp.
Type of Data	-	M	B		2	2	B	F	3	3
No. of Terms	*	4	3				2	3		
R_σ : σBh		X								
σh^2			X			X	X	X		
R_s : γBh^2		X		X	X					
γBhT		X								
γLh^2										
γBhL			X			X				
R_v : γBhv										
$\gamma Bh^{1.5}v\sqrt{g}$										
$\gamma Bhv^2/g$		X						X		
$\gamma B^{1.65}hv$										
$\gamma LB^{.25}h^{.65}v/\sqrt{g}$										
$\gamma B^{1.5}hv/\sqrt{g}$										
$\gamma LB^{.5}h^{.5}v/g$										
Other Combination terms			X	X	X		X	X	X	
COUNTRY	A	F	R	F	A	A	C	C	A	A

Legend: M = Model Scale Data, F = Full Scale Data, B = Both M & F, * = Computer Code Available
Country Code: C=Canada, A=U.S.A., R=Russia(USSR), G=West Germany, F=Finland, UK=United Kingdom
TERMS: R_σ = icebreaking (static), R_s = submersion, R_v = speed dependant terms

the hull, they are pressed against the ship sides. Friction is also often included in the breaking resistance and Milano (1972) even added a separate term to account for the friction as the ship rides up onto the level ice sheet. The large variance in treatment of friction is partially due to the fact that friction coefficients, especially at full scale under interaction conditions, are generally unknown or difficult to measure.

Lewis (1970) included the effects of friction in the empirical coefficients on a purely empirical basis. Later Arctec (1978) introduced the so called geometry-friction coefficients, which are integrated hull form coefficients that include friction effects on both ice fracturing and ice moving functions.

Many different parameters can be included in the ice resistance equation. Several parameters appear consistently in most equations. These are: ice strength in flexure, ice thickness, ice density, water density, gravity, ship beam and ship velocity and the dependent variable of resistance.

Most sophisticated models also try to determine the effect of the hull shape. This is found by terms containing combinations of such variables as entrance angle, stem angle, bow angle, water plane area, and flare angles. Kashteljan (1984) concluded from model testing that the bow flare angle is the most influential ship parameter. Similar conclusions were arrived at earlier by Arctec (1978) when analyzing an extensive model test data base. Most recently Baker (1985) has demonstrated the successful improvement in icebreaking performance of M.V. ARCTIC due largely to an improvement in frame flare angles.

Draft is seldom included in resistance equations. Recent tests by Kashteljan (1984) concluded that draft has no effect on resistance. Length is seldom required and little proof of any significant influence has been found.

Some of the recent contributions to ice resistance responses have been made by various investigators and the most significant works will be reviewed in the following. Efforts have been made to nondimensionalize the resistance usually by dividing it by $\rho_v Bh^2$. This approach has been used extensively by Canadian and U.S. investigators.

Lewis (1982) used full scale trials data from a wide range of ships to find empirical coefficients for a dimensionless resistance equation:

$$\frac{R}{\rho_v g B h^2} = C_o + C_1 \frac{\sigma}{\rho_v g h} + C_2 \frac{V}{\sqrt{gh}} \frac{(L/h)}{(B/h)}^{1/2}$$

The empirical coefficient C_0 is used to account for hull shape, ice strength and friction factors. They found $C_0 = 3.8989$, $C_1 = 0.0123$ and $C = 0.223$. The value of this equation is that, since it was derived from a wide variety of data, it can be applied in a broad range of situations. The dimensionless parameters used in this model are essentially the same as those first proposed by Lewis (1970) except for the last term which includes the length/ice thickness and beam/ice thickness ratios as parameters.

Carter (1983) solved the resistance problem by first finding the static resistance of ice bending and friction and then multiplying by a factor which accounts for velocity affects.

$$R_t = R_{is} \left\{ 1 + \frac{0.4V^2 \, Lc^2}{\sigma t^2} \right\} + R_{ow}$$

where R_{is} is the static resistance which is a function of ice strength, ice thickness, h, characteristic length of ice, L , ship beam B, friction factor, μ, and hull shape. This method is totally analytical and differs in approach from most theories, but correlation with model and full scale data is good as indicated in several reports, e.g. Tatinclaux (1984).

Figure 5.3.6 reproduces Tatinclaux's results for the R-Class icebreaker which illustrates the agreement between resistance measured and calculated.

Mathews (1984) developed a semi-empirical resistance equation from model data of the M.V. ARCTIC, which works well in predicting full scale resistance of the M.V. ARCTIC. Friction coefficients for model and full scale ship must be known and it seems that model data has to be manipulated in order to adjust the coefficients for full scale performance prediction. His model for ice resistance may be given by:

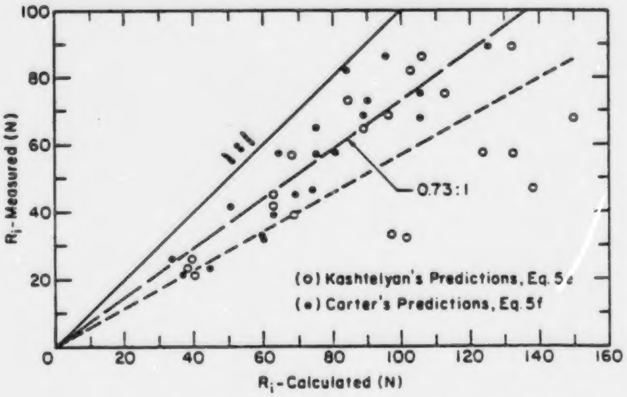
$$R_{ice} = \frac{C_o \, \sigma bh^{1.5} \, g^{.5}}{(E/\rho_i)^{.5} \, V^{.5}} + C_1 \, \rho_i gbh^{1.5} \, (E/\rho_i)^{.25} \, V^{.5} \, (1 + mu)$$

Figure 5.3.7 may be used to illustrate the present state of variability of the predicted resistance values using different methods. It is shown that the predicted resistance may vary significantly depending on the type of model used. For instance Wartsila's model was based on Great Lakes bulk carrier ship shape series. Kashtelan's model has later been corrected for low sensitivity to speed.

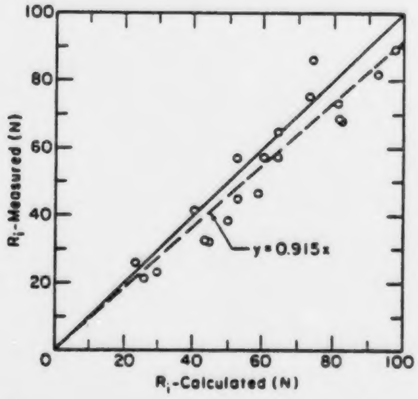
Therefore the presently available and published models which address the ramming performance of ships appear to be capable of providing reasonable prediction of the average speed of advance of an icebreaker or icebreaking cargo ship in the ramming mode of icebreaking.

FIGURE 5.3.6

COMPARISON BETWEEN PREDICTED AND MEASURED ICE RESISTANCE



(a) Comparison between ice resistance measurements and predictions by Kashtelyan's (Kashtelyan et al. 1968) and Carter's (1983) equations.



(b) Comparison between ice resistance measurements and predictions by Carter's (1983) equation with E/σ=5000.

b) Thick Level Ice

Of particular interest is the hull performance prediction during ship operation in heavy ice conditions which exceed the continuous mode capacity of the ship. In that case the ship is forced to operate in the ramming mode. The basic problem in ramming is that of solving an unsteady or transient motion which depends on the ice resistance and varies with thickness, strength, etc.

Lewis (1970) solved this problem for bollard thrust conditions and resistance dependence on v^2. Petrov and Kheysin used the resistance as a function of v and v^2 and obtained a solution by Eulers' graphic method. Nawwar (1984) has developed a general solution of the ramming problem which assumes a general thrust and resistance formulation and accounts for ship acceleration in the broken channel, backing in the broken channel, stopping, engine reversal, as well as penetration of the unbroken ice. The model offers a comprehensive closed form simulation and has been successfully applied in several occasions to optimize or evaluate the ramming procedures for icebreakers or icebreaking cargo ships, e.g. Arctec (1984).

c) Ridged Ice Performance

Perhaps the first detailed analytical model developed for first year ridge penetration was that by Keinonen (1979). The model is analytical and is based on data obtained on the icebreaker APU in the Baltic Sea (1975).

Keinonen has split the ridge resistance into three components: level ice resistance, aging resistance and pure ridge resistance. For level ice resistance he uses commonly available models for Baltic ice without any speed dependence. He also ignores the aging resistance and assumes it to be a constant. While this approach may be valid for Baltic conditions it will not be suitable for Arctic pressure ridges which vary significantly in the age and degree of consolidation. Thus the model is only concerned with the pure ridge resistance.

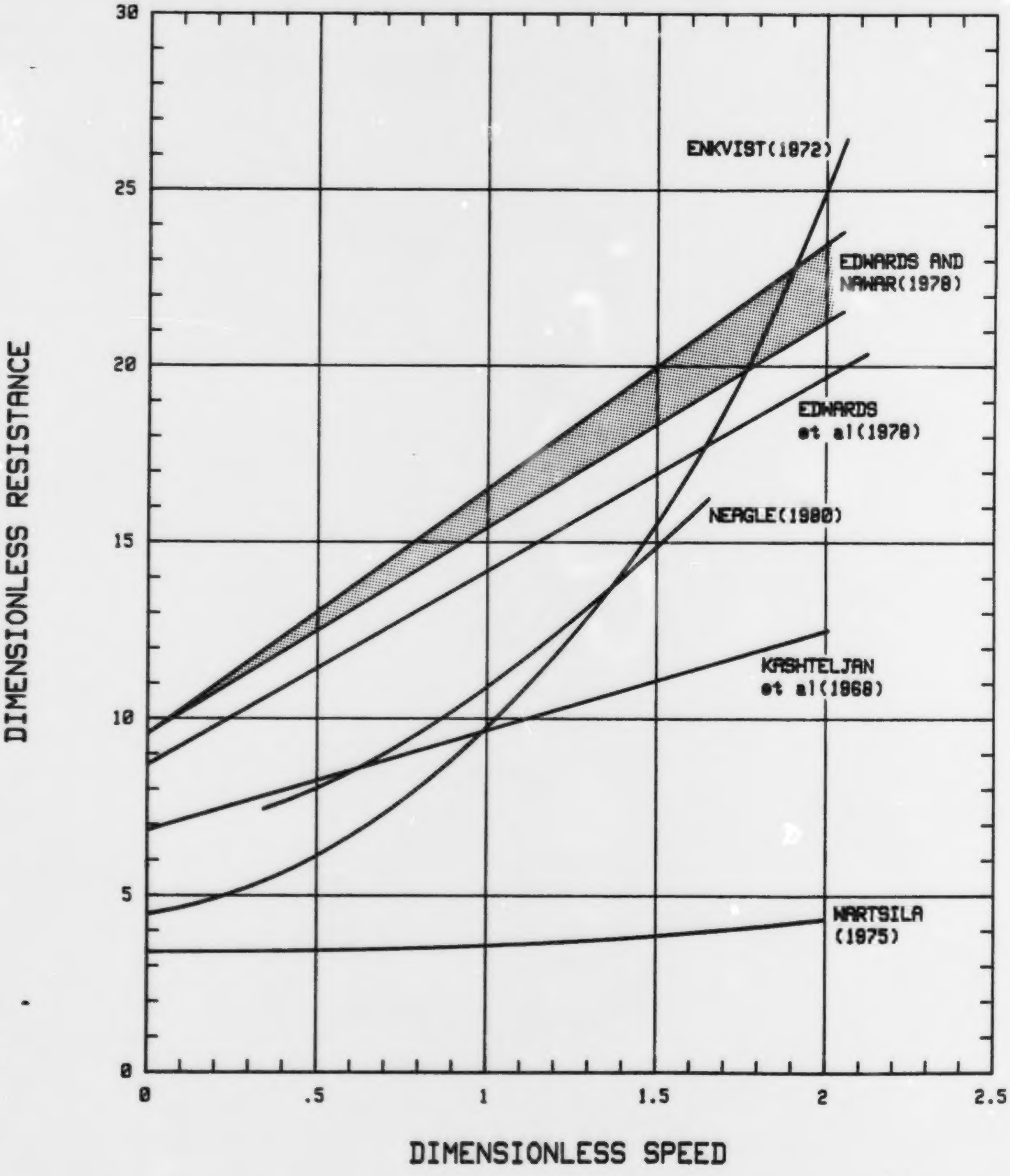
Comparison of the model with model or field observations have indicated large deviations of up to 102%. These were attributed to the lack of knowledge of ridge characteristics, and the effects of idealized theoretical modelling of the process and the ridge.

Other models have been proposed by Peirce (1978) and others. However, these proposals have not been verified by either field or laboratory model test data.

Most recently Tunic (1984) has proposed a method to predict ship performance in pressure ridges. He idealized the ridge with a rectangular cross section and flat keel using overall similar proportions of ridge depth to ice thickness and ridge width to depth. Assuming a ridge field with varying intervals between ridges he used the principles of kinematics to simulate ship acceleration/deceleration as it traverses a ridge field. His solution assumes the ridge to be equivalent to thick level ice and uses level ice resistance equations to estimate the ridge resistance. Tunik

FIGURE 5.3.7

COMPARISON OF VARIOUS LEVEL ICE RESISTANCE MODELS



BASIS - LOUIS S. ST LAURENT LINES
- ICE STRENGTH: 556kPa (80psi)
- ICE THICKNESS: 1.0m (3.3ft)

provides some useful data which illustrate the effects of ridge spacing, ice thickness, ridge thickness and ridge proportions on the performance.

Unlike Keinonen, Tunik's model does not address the detailed ship penetration performance of a ridge and evaluates performance in a more global sense. An almost identical analysis, rather more comprehensive, was performed in connection with the Arctic Pilot Project transit simulation model, which is still subject to a confidentiality agreement. Arctec has also performed a number of studies to develop analytical and semi-empirical models for ridge penetration performance of first and multi-year pressure ridges. Such models incorporate "real" ridge shape, type, age, degree of consolidation and strength parameters. These studies are proprietary.

Another potential model was proposed by Edwards (1979) which suggests handling the ridge penetration problem as a variable thickness problem and incorporates the thickness gradient as a parameter in a more general resistance equation.

d) Brash Ice

Mellor (1980) found an analytical expression for the resistance of a ship in brash ice just on the verge of motion:

$$R = [1 + 2 \ (L_1 1/B = L_2 N/B) \ b \ R_p$$

Both Mellor (1980) and Greisman (1981) treated brash ice as a Mohr-Coulomb solid (or a soil) in their analyses. Greisman expanded on the work of Mellor, Keinonen and Nyman (1978) to find an expression for the resistance of a moving ship. Greisman (1981) found that below a certain critical velocity the resistance is constant.

In his formulation the resistance was not a function of ship beam or hull shape although there was one speed independent term and one speed dependent term.

Milano [1975] performed an analytical study on the resistance of brash ice that was similar to his analysis of resistance in level ice. He observed from full scale testing that the breaking pattern of refrozen brash ice was similar to that of level ice. His curve of resistance versus ship speed has a knuckle at the point where penetration distance of the ship is such that the ship has penetrated to its maximum beam. After this point resistance does not increase as rapidly since the length of the ship on which it acts remains constant.

5.3.4.3 Empirical Analysis

a) Thick Level Ice

Ionov (1984) analyzed icebreaker performance in the ramming mode experimentally. In their evaluation, they blended the ice roughness e.g. pressure ridges, into an average or smoothed ice thickness. This parameter was based on the penetration distance after each ram, and hence would be variable and ship related. A similar approach was used by Makinen (1975). Ionov used a kinematic analysis which takes into account the trajectory of the instantaneous velocity centre displacement and the trajectory of displacement of the icebreaker centre of gravity during ramming. Hence records of angular displacement (pitch) and linear acceleration (surge and heave) recorded at two points along the ship length were used in this analysis. Lateral accelerations and displacements were neglected. As a result of their analysis they developed a number of empirical formulae which are valid for an icebreaker of 20,000 - 40,000 hp. They also analyzed the cycle time components on empirical basis.

While comparisons of the general trends observed by Ionov (1984) with the model developed by Arctec (1984) indicate excellent corroboration, there has been no detailed analysis or comparison of the empirical versus analytical models.

Therefore, the presently available and published models which address the ramming performance of ships appear to be capable of providing reasonable prediction of the average speed of advance of an icebreaker or icebreaking cargo ship in the ramming mode of icebreaking.

b) Ridged Ice

Empirical models for pressure ridge penetration resistance or breaching energy requirement have been developed in conjunction with model tests performed to evaluate specific hull forms. Such models have no general applicability.

It should be noted that model testing of pressure ridges is still in its very early stages. The technology of building pressure ridges in model scale is not well developed and various model test facilities have developed their own techniques for simulating ridges. The difficulties arise from the fact that profiles of pressure ridges in nature are greatly variable, therefore, the selection of a representative model ridge is somewhat arbitrary. Also the modelling techniques for ridge strength gradients and depth of consolidation are not well developed. No published information has been found to document such techniques.

Several ships have been tested in pressure ridges in various areas of the Arctic. These include:

- CCGS LOUIS S. ST. LAURENT
- M.V. ARCTIC
- USCG Polar Class icebreakers
- Canmar's icebreakers including KIGORIAK

While some of these data exist for continuous navigation through smaller pressure ridges, most pressure ridge penetration involves ramming operation. Experiences on the M.V. ARCTIC indicate some similarities between ramming thick level ice and pressure ridges.

Kashteljan et al have proposed a method for predicting the effect of hummockiness on an icebreaker performance. In 1 meter thick ice the ship may be able to proceed at 5 knots in level ice. For average hummockiness, measured on a qualitative scale from 0 to 5 points, the speed drops to 1 knot and further ice roughness will force the icebreaker to resort to ramming.

This approach is qualitative but practical and is based on many observations. However, a large number of nomograms will be required to cover every class of ships.

c) Coarsely Broken Ice

Large broken ice fields include naturally broken ice ranging in size from 20 metres to several hundred metres. Larger floes may be treated as level ice, but the threshold will be dependent on the size of the icebreaking ship. The only available analysis for ship resistance during motion in such conditions is purely empirical and is based on full scale measurements and model experiments in broken ice.

Earlier work in the 1950's is attributed to Nogid, and other Russian investigators. Kashteljan (1968) proposed the following equation based on 500 observations on the icebreaker ERMAK:

$$R = \text{Const.} \times (C_K + 9\, v^{1.3})\, h^{1.2}$$

where Const. is an empirical factor based on the ship beam

C_K is a function of the floe size,
v is the velocity of the ship,
h is the ice thickness.

Gill (1981) modified this formula as follows and introduced a reduction factor for the ice concentration, C_{con}.

$$R = C_{con} \times 3.77\ (10B)\ h^{1.2}\ (C + 9.0\ v^{1.3})$$

They used the following values for C_{con}: 1, 0.67, 0.5, 0.33 for concentrations of 9, 8, 7 and 6 tenths. It has been generally observed that the ice resistance in lower concentrations than 0.6 are insignificant.

d) Finely Broken Ice

Finely broken ice is defined as ice having piece size in the range from 2 to 20 metres. Based on Ryvlin's Ph.D. Thesis (1963), and later work by Russian investigators, an empirical model has been developed for finely broken ice. This model is slightly different from that proposed by Dubrovin (1970) but essentially having the same structure without the ice compression term or the linear dependence on Froude number. In view of the empirical nature of the models the differences in terms or coefficients can be understood.

e) Brash Ice

A more recent area of research, although some earlier investigation was conducted by Kashteljan (1968), is ship behaviour in brash ice. Brash ice is defined as ice pieces 2 m or less in length. It is formed in shipping channels from the passage of vessels through level ice. With each ship passage the pieces become rounded and more uniform. Brash ice is restrained from spreading out by the level ice which forms the side walls of the channel so it is usually more than one layer thick (Greisman, 1981) and is usually thickest at the side walls.

The strength of brash ice is only slightly increased by refreezing. Its main strength is from its depth which increases through repeated passage of ships (Greisman 1981).

Levine (1974) found the resistance of a Great Lakes cargo vessel, operating in brash ice, to be:

$$R = 1.29 \quad {}_{i}gBh^{2} + 1.365\ V^{2} \quad {}_{i}Bh$$

This form is very similar to the empirical equation used by Vance (1980) to describe the resistance of the icebreaker USCGC "KATMAI BAY" during full scale trials in brash ice. The formula he used to fit the data was:

$$R = C_{1} \quad g\ Bh^{2} + C_{2} \quad {}_{i}V^{2}\ LB^{0.35}\ h^{0.65}$$

with C_1 and C_2 varying with brash ice thickness. The first term in Vance's equation is identical in form to that of Levine.

Kitizawa (1985) conducted an experimental study in brash ice using two different bows: a wedge shaped bow and an icebreaker bow. They found the resistance was almost linearly proportional to the ice thickness. They compared their experimental results with published prediction formulae. The formula proposed by Levine (1974) matched the data well. Mellor's (1980) relationship underestimated the resistance, Greisman's formula, including his assumption that the brash ice behaves as a Mohr-Coulomb solid below a critical speed, matched the wedge-bow hull data well. Figure 5.3.8 is a comparison of experimental results with various predictive models.

5.3.5 Information Deficiencies

The deficiencies in relation to hull design and performance are in the two areas of optimising the shape of icebreaking ships and in predicting accurately the performance in a range of ice conditions. The benefits which can result from research in this area are substantial and can greatly influence the economic viability of future Arctic shipping systems.

a) There is a need for verification of the fundamental assumptions usually made in theoretical level ice prediction models so that the proper breakdown of resistance components can be made by source.

b) A level ice performance prediction capability should be developed based on the known full scale performance of icebreaking ships. The international database is substantial but disorganised and presently unsuitable for use in this manner. The known performance must be related to hull form and size and to the predicted performance based on model tests. Model tests may be used to complete the family of performance data which can be used for interpolation or extrapolation to make accurate predictions for future ships.

c) The optimum hull form for Arctic ships depends on the ships mission profile and to some extent the cost of construction. The search for an optimum shape should continue, learning from the experience of the last ten years. A programme of hull form optimisation should be encouraged, covering the needs (sometimes different) of icebreakers and icebreaking cargo ships.

d) The present inability of model ice to correctly simulate the breaking patterns and strength of the ice leads to uncertainty when using model tests to predict the performance of ships. Although much research has been completed in this area, and progress is being made, the problems are far from solved. Some of the most recent work has highlighted the inability of model basin tests to accurately simulate full scale.

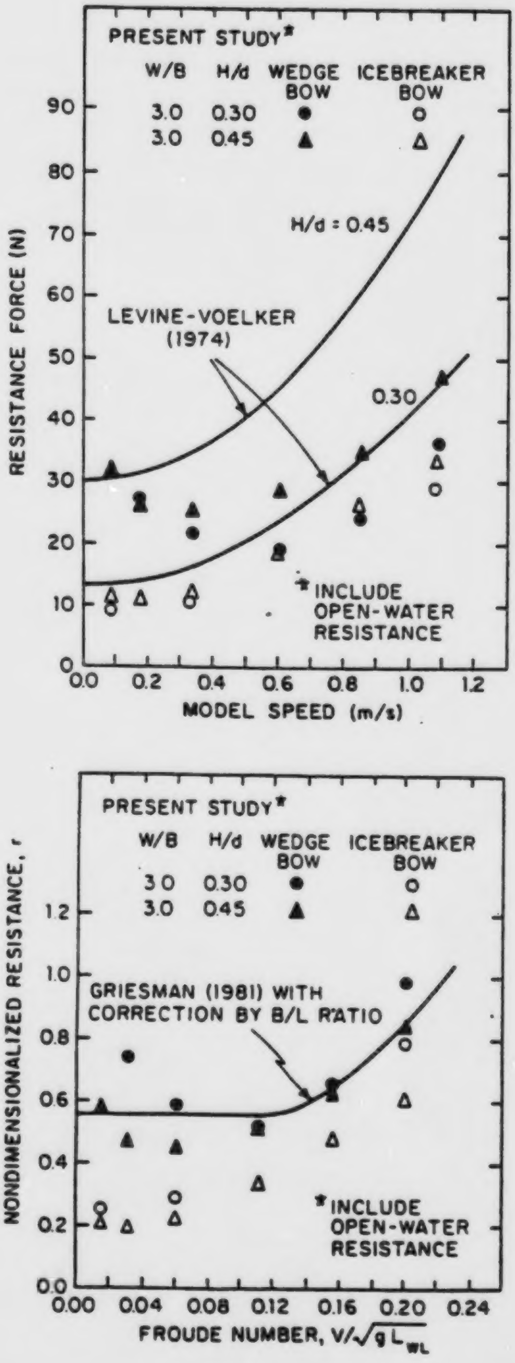
e) An improved procedure is required for monitoring model ice strength parameters in the same time frame and at the same speed as the ship model is being run. This procedure would relate, more accurately, the ice strength to the model shape, and make adjustments for the effect of shape on the model test results.

f) The present understanding is poor of the effects and importance of friction on the results of model tests. The important aspects of this problem relate to both full scale and model scale friction. Present techniques attempt to either simulate correctly the friction coefficient, or run the tests at a nominal value and correct the results for the type of ship being tested i.e., new and old. A programme of research should be initiated to determine at full scale the magnitude of the friction forces, and how, at model scale, to simulate those forces.

g) Recent work on the hydrodynamics of model ships in ice has shown that the thrust deduction factor may not be properly simulated. These recent results have indicated descrepancies of up to 400 percent of the value which is obtained during clear water model tests. This difference has a large impact on the prediction of performance at full scale and therefore on the power which may be installed as a result of those tests.

FIGURE 5.3.8

COMPARISON OF BRASH ICE RESISTANCE RESULTS AND PREDICTIONS



h) An analysis of existing data on the level ice ramming capability of icebreaking ships will be a starting point from which a better understanding may be gained of overall ramming performance. The available data should be assembled and, along with details of the ships, used to begin the development of a ship ramming performance prediction model.

i) Ship performance in ridges has received very little attention in the past. Ridges are much more complicated ice features than level ice, and, despite the many years of work on the latter, there is still no accurate model for performance prediction. The areas which require further investigation include:

- ship/ridge interaction mechanisms,
- pressure ridges, failure modes,
- development of simplified algorithms for prediction of ship performance,
- development of methods for modelling pressure ridges at model scale.

j) Experience of model resistance and 'English style' self propulsion tests, during which the model is restrained in the fore and aft direction, has demonstrated that the data is influenced by vibration of the carriage and towing post. Particularly, the towing post has been identified as the major source of problems during tests which try to simulate to the greatest extent possible the true forces acting on the ship at full scale.

5.4 Propulsion

5.4.1 General

The propulsion characteristics of existing icebreakers and icebreaking cargo ships provide some insight on how the technology of icebreaking propulsion is changing. To illustrate several interesting points, power per shaft versus year of construction has been plotted in Figure 5.4.1. This parameter is plotted to illustrate any trends which may be apparent as icebreakers have developed since 1940. Icebreakers and icebreaking cargo ships are included and those ships with propeller nozzles, cp propellers and mechanical transmission, and various electric transmission are highlighted.

The Figure shows the power per shaft increasing over time. Each increase appears to be driven by Soviet vessels although the LEONID BRESHNEV was delivered two years after the slightly lower powered (power per shaft) POLAR STAR. In 1986 the power per shaft was dramatically increased by almost 100%, from 16.65 MW to 29.42 MW when the Soviet LASH vessel was delivered.

Until 1966, DC-DC electric transmission was the most common system in use and continues to be used. However, DC-DC systems have begun to give way to AC-DC, and AC-FFC-AC. Since 1975, several vessels have installed these systems. The largest AC-DC system at 16.65 MW per shaft are installed on the Soviet SIBIR class, and these continue to be the largest electric propulsion systems on pure icebreakers. The largest AC-FFC-AC system on an icebreaker, at 7.5 MW per shaft, is installed on the OTSO, although a larger system at 12.5 MW per shaft is on order for the new TAIMYR class icebreakers.

There is now a steadily increasing number of ships fitted with cp propellers and mechanical transmission. The first was installed in 1966, and since then many ships have used this form of propulsion. The Soviet LASH vessel not only increased the power per shaft by a factor of two but placed all of the ship's propulsion power on one shaft and utilised a cp propeller.

Since 1978, propeller nozzles have begun to appear regularly on icebreaking ships. Until the Soviet LASH vessel was delivered in 1984, only ships with an installed power less than 15 MW had been fitted with nozzles and all of those were Beaufort Sea ice management/supply vessels.

The selection of a suitable propulsion system for an ice class ship must be based principally on an analysis of the intended function of the vessel. The type of systems to be considered for such diverse ship types as dedicated icebreakers, bulk cargo ships, tugs, supply vessels, dredgers, etc., may be discrete to the mission profile and power requirement of the particular ship. However, some requirements will be common to all vessels.

Reliability - To ensure ship safety when navigating in Arctic ice, full power must be available on demand, and a better than average redundancy allowance should be incorporated in the system.

Flexibility - For ships which are designed to operate both in open water and in severe ice conditions, the system must be able to operate continuously and economically at a range of power levels required by the mission profile.

When a large range of power is required, multiple engine or combined system installations permit the number of engines to be run as required by the conditions to achieve the best fuel efficiency.

Manoeuvrability - The propulsion system must be able to change load, power and speed rapidly. This characteristic is more important for all ice class ships but of most importance to dedicated icebreakers.

High Power to Weight Ratio - The propulsion system should be as compact and light as possible.

Maintainability - The principal machinery must be able to be maintained and repaired as necessary by the ship's operating engineers if 'normal' faults or damage occur.

While there are many combinations of primemovers, transmission systems and propellers which could be proposed for a given ship, very few systems would fit a given mission profile or would seriously be considered for detailed evaluation. Those which could seriously be considered are illustrated on Figures 5.4.2 and 5.4.3.

The components of these systems must be designed to meet the special requirements of icebreaking ships. Those requirements and the important propulsion system components are discussed in the following text.

5.4.2 Propellers

Fixed pitch (FPP) and controllable pitch propellers (CPP) have been fitted to Arctic ships. Fixed pitch propellers have been used for many years, and continue to be used on most icebreaking ships, although since 1966 controllable pitch propellers have seen increasing use on a wide range of icebreakers and icebreaking cargo ships. The relationship for some existing icebreaking ships between propeller power and diameter is shown in

FIGURE 5.4.1

POWER PER SHAFT VERSUS YEAR OF CONSTRUCTION FOR ICEBREAKING SHIPS

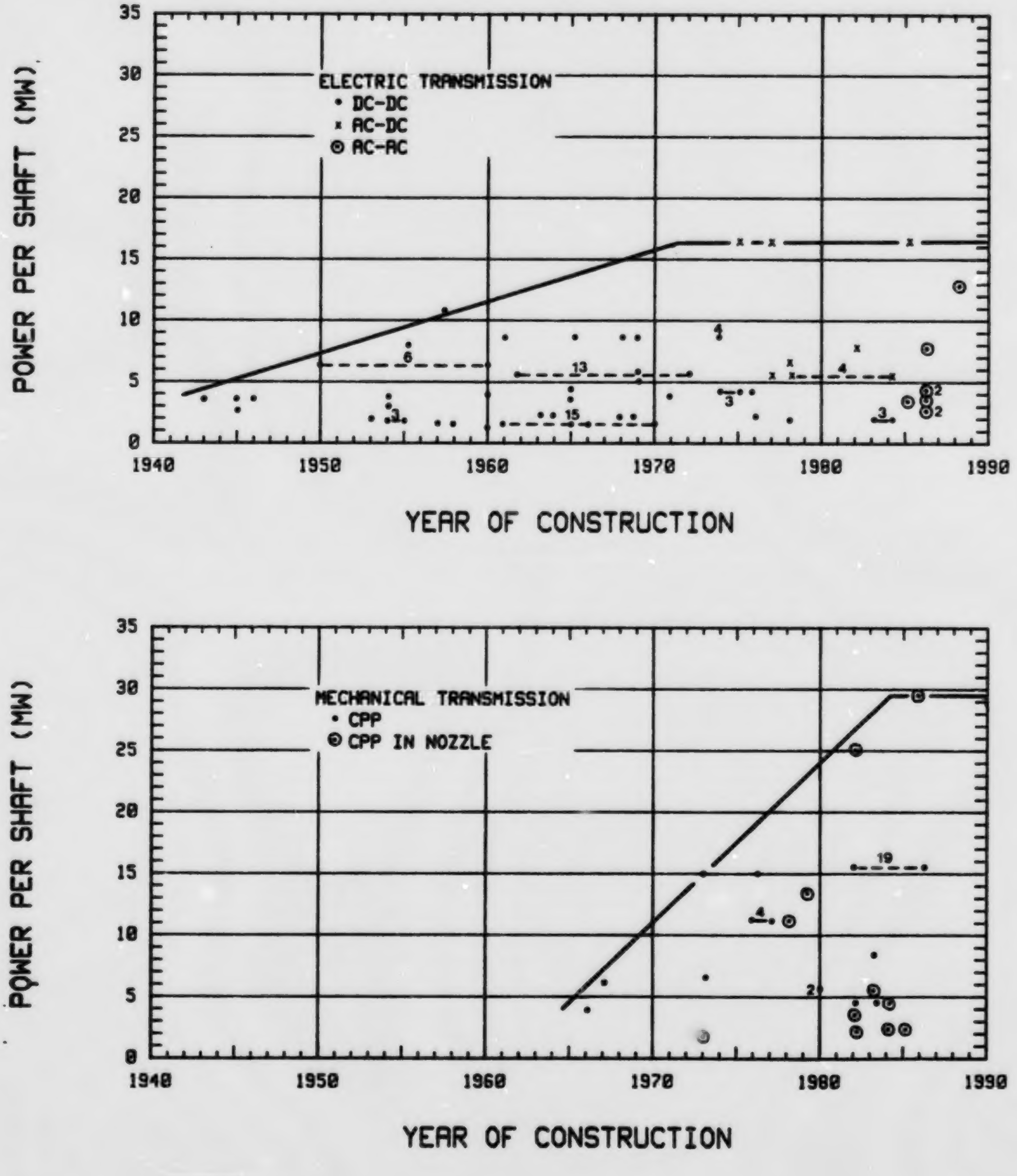


FIGURE 5.4.2

MEDIUM AND SLOW SPEED DIESEL ENGINE SYSTEMS FOR ICEBREAKING SHIPS

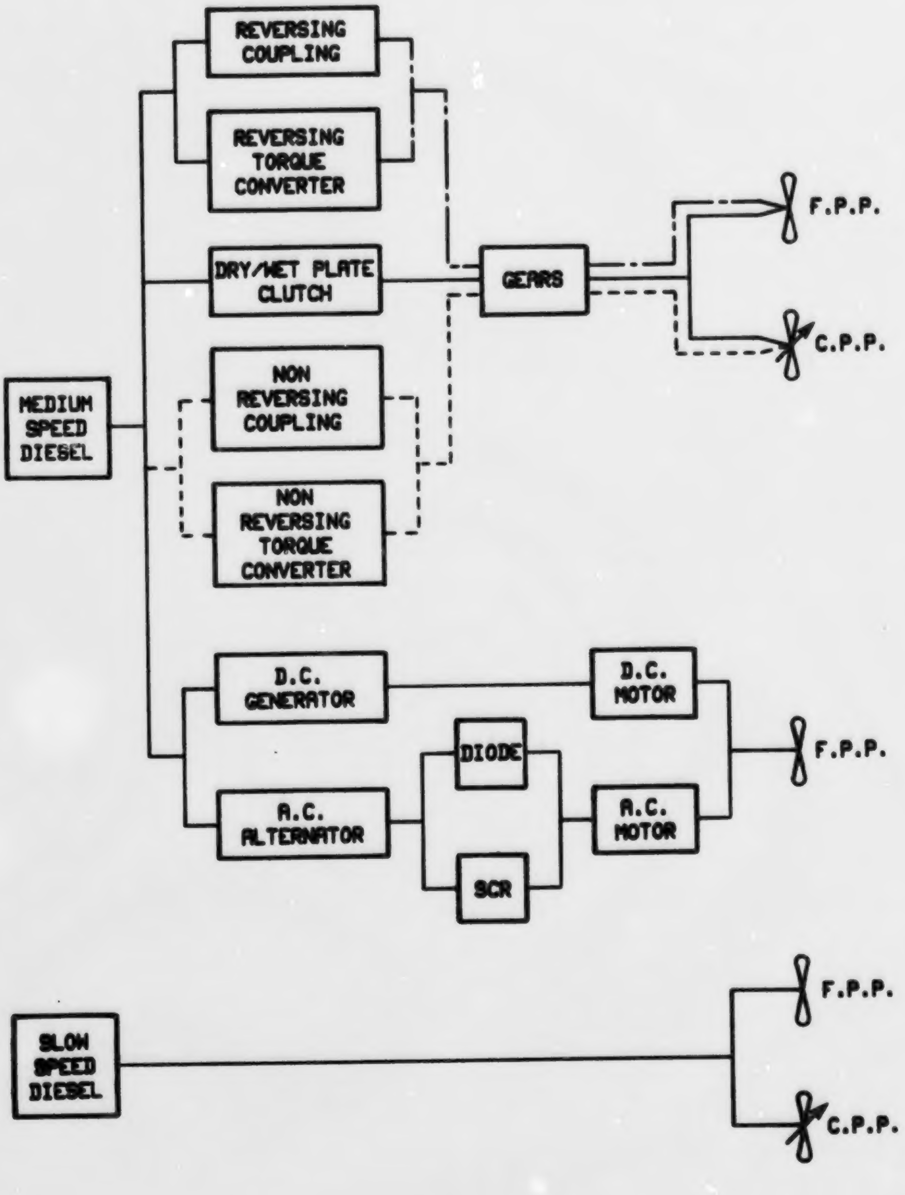

REVERSING COUPLING
REVERSING TORQUE CONVERTER
DRY/WET PLATE CLUTCH
GEARS
F.P.P.
C.P.P.
NON REVERSING COUPLING
NON REVERSING TORQUE CONVERTER
MEDIUM SPEED DIESEL
D.C. GENERATOR
D.C. MOTOR
DIODE
SCR
A.C. ALTERNATOR
A.C. MOTOR
F.P.P.
SLOW SPEED DIESEL
F.P.P.
C.P.P.

FIGURE 5.4.3

STEAM AND GAS TURBINE SYSTEMS FOR ICEBREAKING SHIPS

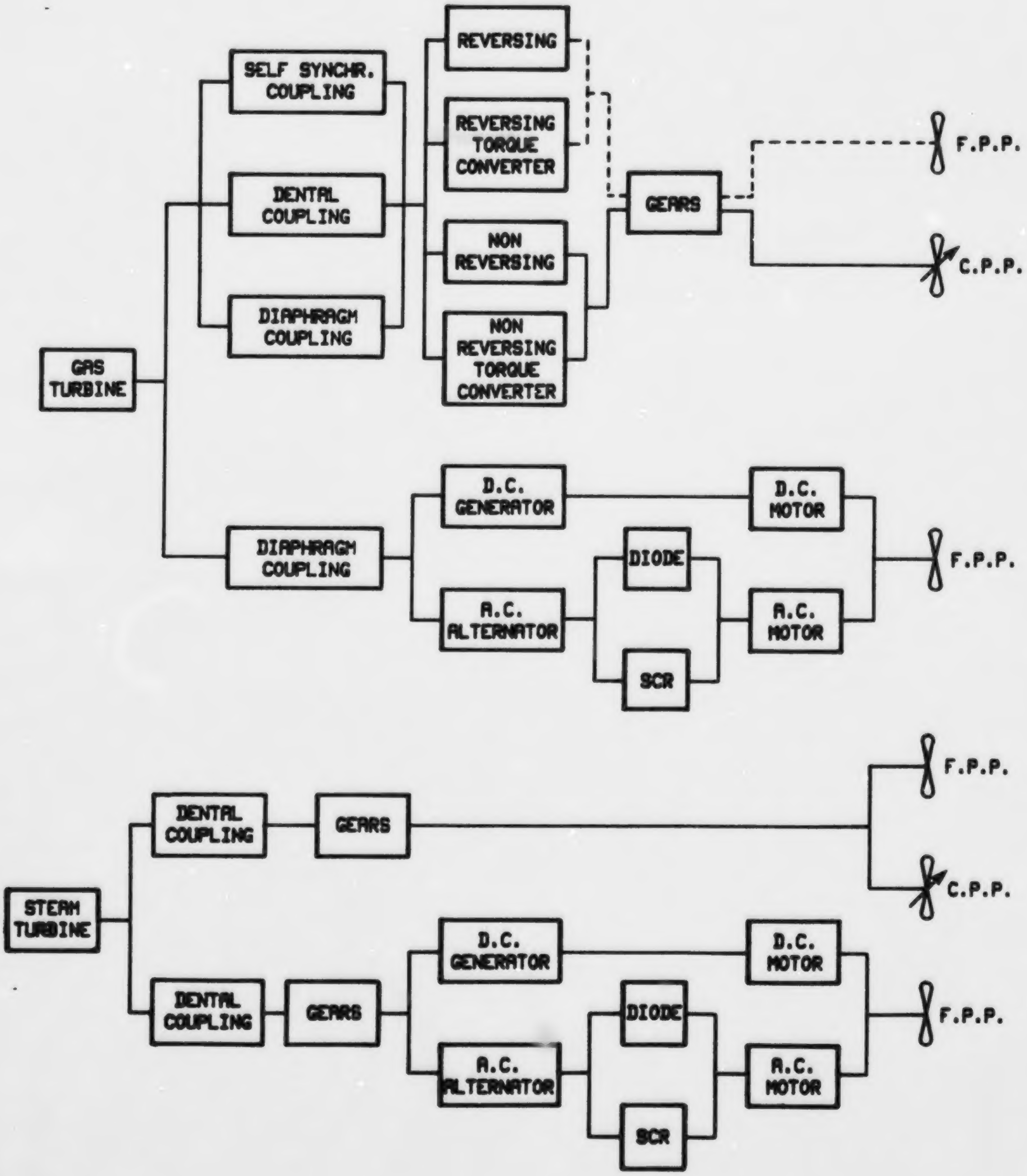

GAS TURBINE
SELF SYNCHR. COUPLING
DENTAL COUPLING
DIAPHRAGM COUPLING
REVERSING
REVERSING TORQUE CONVERTER
NON REVERSING
NON REVERSING TORQUE CONVERTER
GEARS
F.P.P.
C.P.P.
DIAPHRAGM COUPLING
D.C. GENERATOR
D.C. MOTOR
A.C. ALTERNATOR
DIODE
SCR
A.C. MOTOR
F.P.P.
STEAM TURBINE
DENTAL COUPLING
GEARS
F.P.P.
C.P.P.
DENTAL COUPLING
GEARS
D.C. GENERATOR
D.C. MOTOR
A.C. ALTERNATOR
DIODE
SCR
A.C. MOTOR
F.P.P.

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Figure 5.4.4, with FPPs and CPPs clearly identified, and the most interesting ships highlighted.

These two types of propellers presently meet the needs of Arctic ships and selection of propeller type is dependent on the propulsion system. Non-reversing transmission systems, such as diesel geared or gas turbine/geared, may use CPPs to obtain astern thrust and to ease the potential overtorque requirements. Reversing transmission systems, such as any of the electric systems, may use FPPs since overtorque is less of a concern to electric systems.

Irrespective of which propeller type is selected, the design requirements will depend on the vessel's mission profile and will be more onerous than for non-ice transitting ships. The aspects which influence the design of Arctic ship propellers are;

- the loads and strength requirements,
- selection of materials, and
- the affect of nozzles.

5.4.2.1 Loads and Strength Requirements

Interaction of propellers with ice is of two types: ice milling and ice impact. Ice milling occurs when the mass of ice is large or when an ice block cannot move freely, such as when trapped between the hull and the propeller. When ice is milled it is being either crushed or sheared by the blades of the propeller. This is illustrated in Figure 5.4.5. The load caused by ice milling could be high and cause propeller damage.

Ice impact is generally caused by ice pieces of comparatively small dimensions that are either accelerated through the propeller or thrown out radially and pushed around the edge of the propeller disc. The load due to ice impact is relatively moderate, but is expected to occur more frequently.

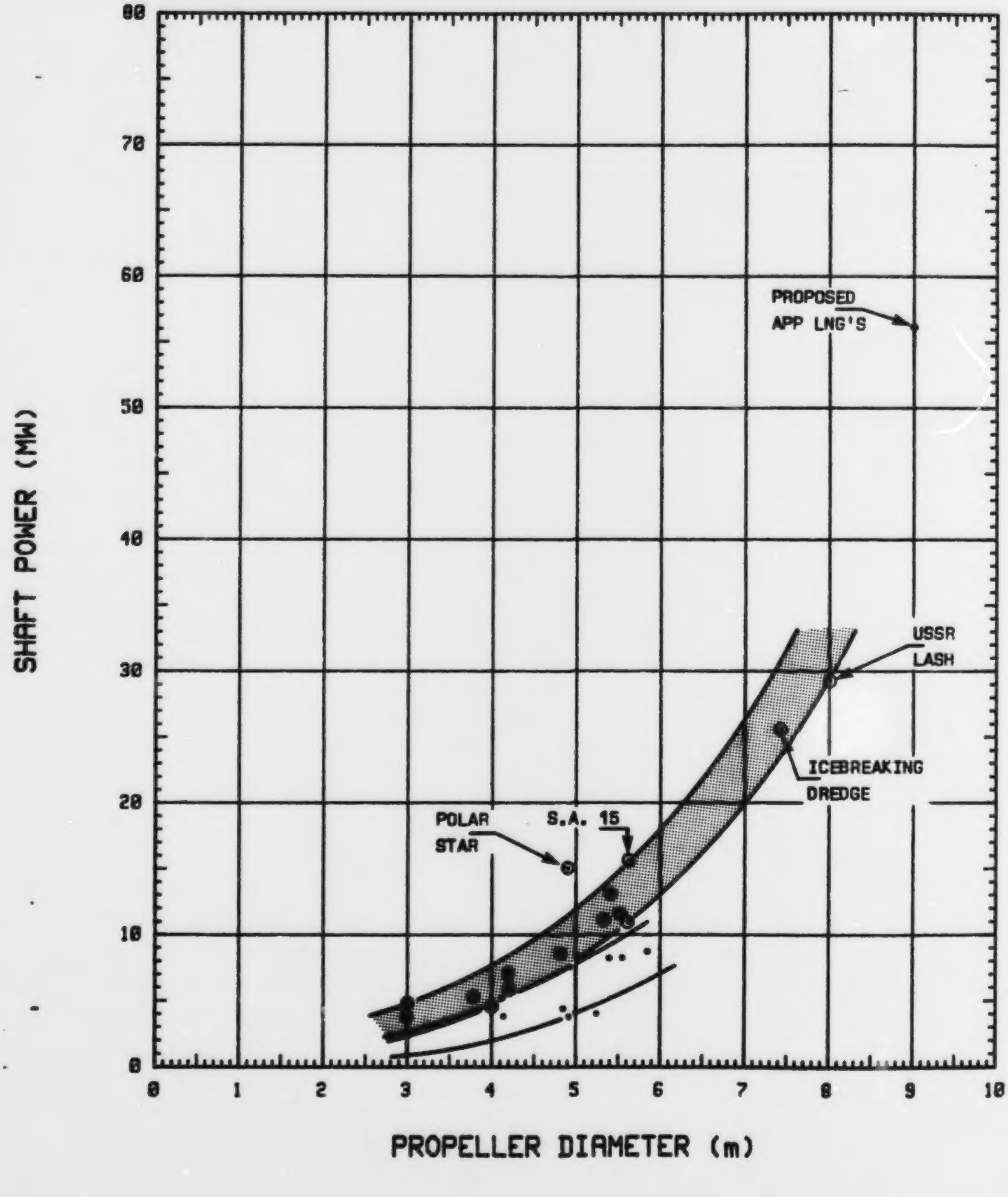
For ducted propellers, the occurrence of ice milling is less and the ice load is expected to be lower compared to non-ducted propellers due to the restrictions on the size of ice fragments imposed by the nozzle. However, periodic loads up to 3 times normal have been measured.

The ice load on a propeller blade depends upon many factors. For ice milling, the strengths of the ice and the conditions of pitch, rpm, ship speed, and depth of cut are the key factors, while for ice impact the load is mainly determined by the size and speed of the ice and system enertia.

A considerable amount of effort in full scale measurement, model scale experiment and analytical study has been devoted to this subject since the sixties. However, because of the complexity of the ice interaction process and the limited knowledge of ice pressure under various loading conditions, the ability to determine accurately the ice milling/impact loads is not well developed.

FIGURE 5.4.4

SHAFT POWER VERSUS PROPELLER DIAMETER FOR ICEBREAKING SHIPS



- Fixed pitch

⊙ Controllable pitch

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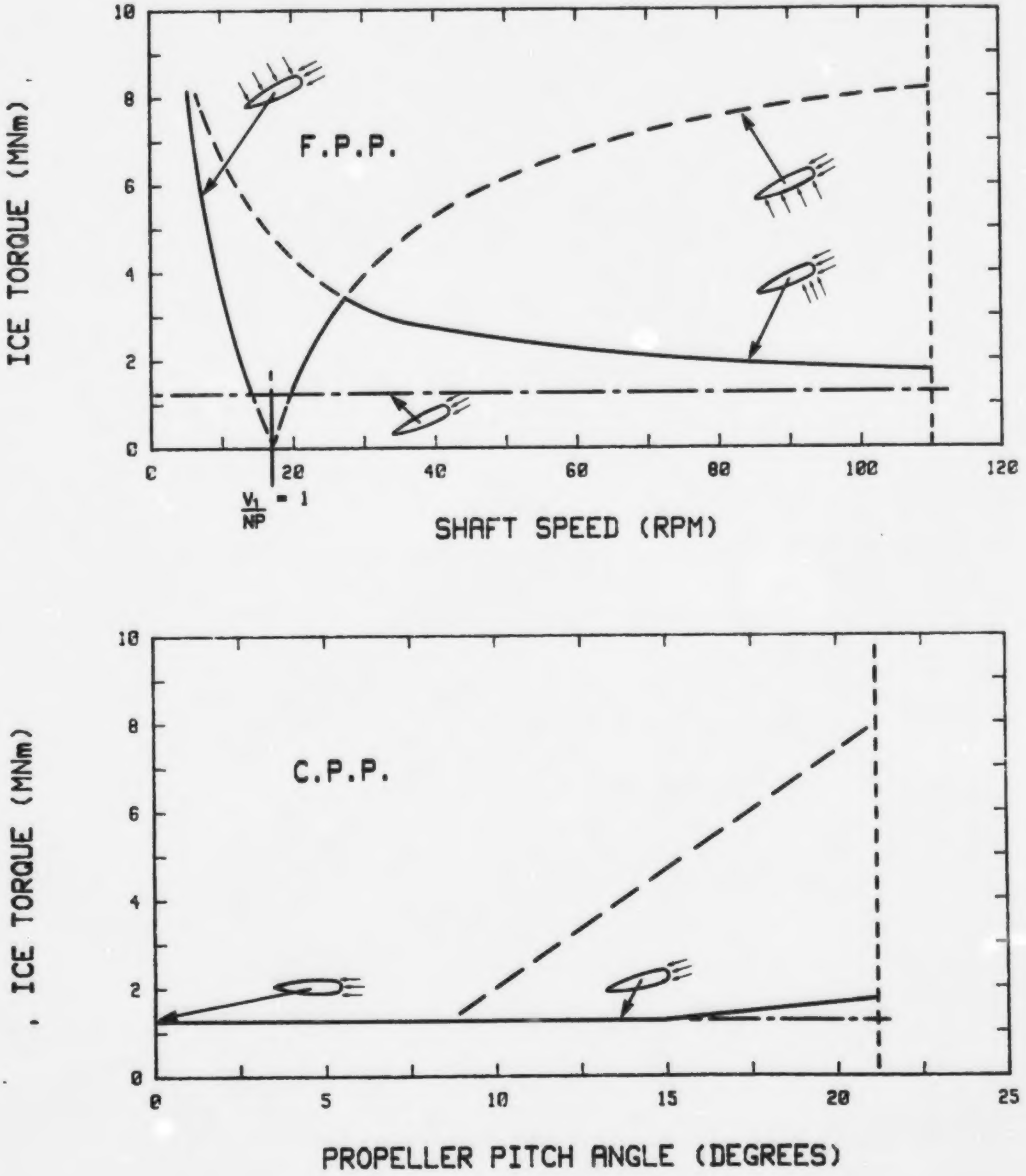
FIGURE 5.4.5

ICE TORQUE VERSUS RPM AND PITCH



The analytical method commonly used for ice torque evaluation is the ice milling model proposed by Jagodkin (1963). His model determines the ice force opposing the rotation of the propeller with a simplified blade geometry and ice pressure assumption. The model is valid within the range of operating conditions for which the model has been calibrated against empirical data. The force opposing rotation is developed by: (a) the action of the blade edge shearing ice and, (b) the crushing by the projected area of the blade section.

Plots of ice torque versus shaft RPM for an FPP and ice torque versus pitch angle for a CPP are shown in Figure 5.4.5.

Recent developments of the propeller ice milling research have extended the determination of ice force and moment in all directions under all possible conditions of interaction using the techniques of model testing, computer simulation and finite element analysis (Edwards, 1976; Melville, 1980; Wind, 1983).

The axial momentum theory recently published by Wind (1983), in his analysis of blade strength and hub requirements, may represent the typical method for deriving the ice load due to impact.

The design of an ice-strengthened propeller has to meet, as a minimum, the dimension and strength requirements of the classification societies stability regulations (CASPPR).

Most of the classification societies have rules for the strength of propellers in the lower ice class categories, either for General or Northern Baltic Services. Requirements for propeller scantlings in the higher ice class categories are generally referred to the rules provided in CASPPR. The CASPPR and Northern Baltic Services rules are based upon the principle of ice torque, in which the additional blade thickness requirements for ice load are determined by an ice torque index which depends on the ice class and the square of the propeller diameter.

From the present ship operation experience in the Arctic, the CASPPR propeller scantling requirements are seen to be sufficient in the lower ice class categories. However, it has been shown (Wind, 1983) that in the higher ice class/power categories, the CASPPR propeller scantling rules may not be adequate. This is made clear when comparing the CASPPR and USSR ice rules for propellers. It can be seen from Figure 5.4.6 that, in terms of propeller section strength requirements, the USSR rules are more stringent for higher power ships and, conversely, the CASPPR rules are more stringent for ships of lower power.

This also appears to be reflected in the newly proposed ice rules of ABS for ships operating in Arctic and Antarctic waters. In the new ABS rules an increasing factor has been incorporated in the blade strength requirement calculations for ships of shaft power in excess of 10,000 hp. This is illustrated in Figure 5.4.7. The required blade section modulus has been increased substantially for high power icebreaking ships.

FIGURE 5.4.6

COMPARISON OF CANADIAN AND USSR
PROPELLER BLADE STRENGTH REQUIREMENTS

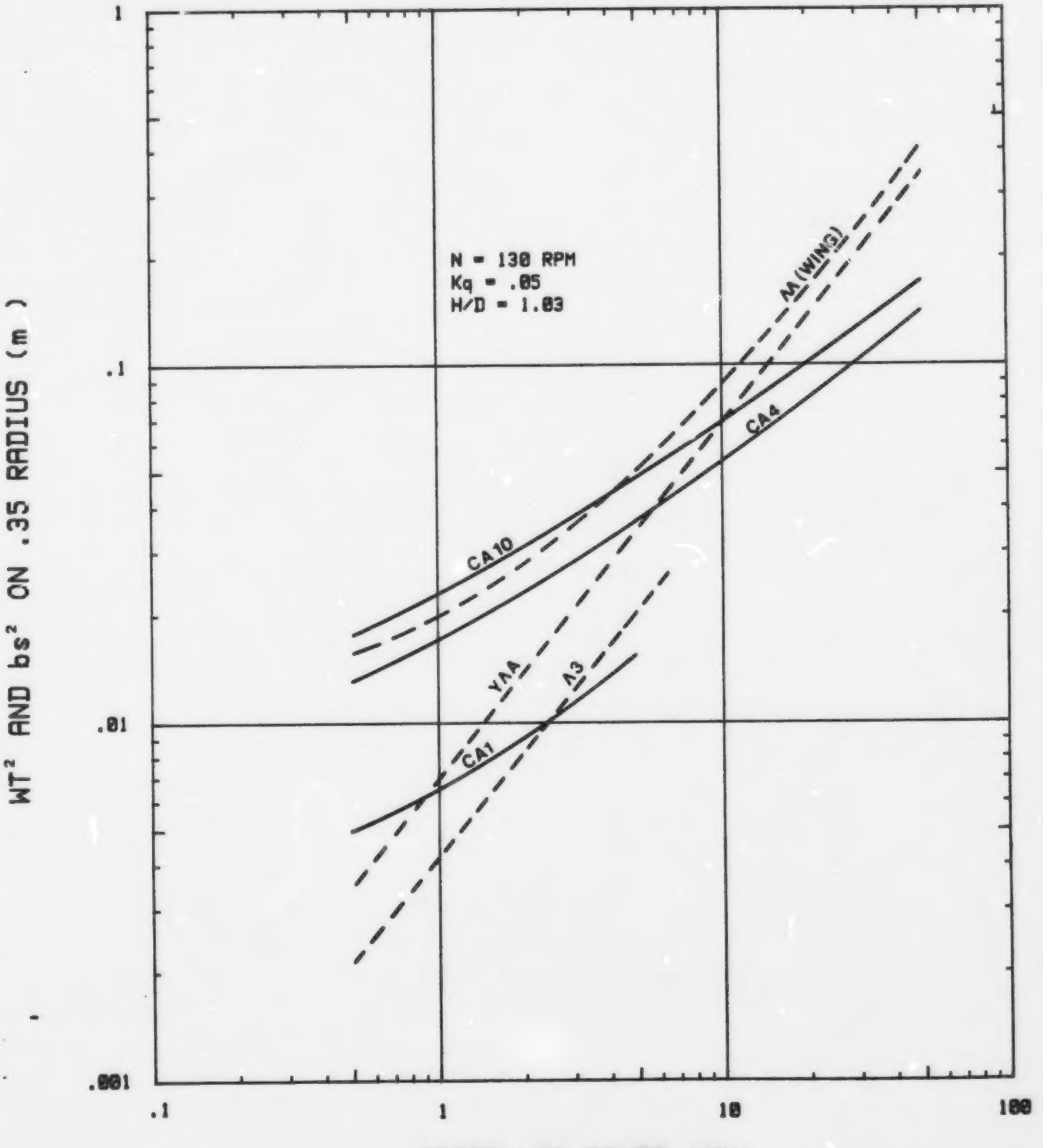
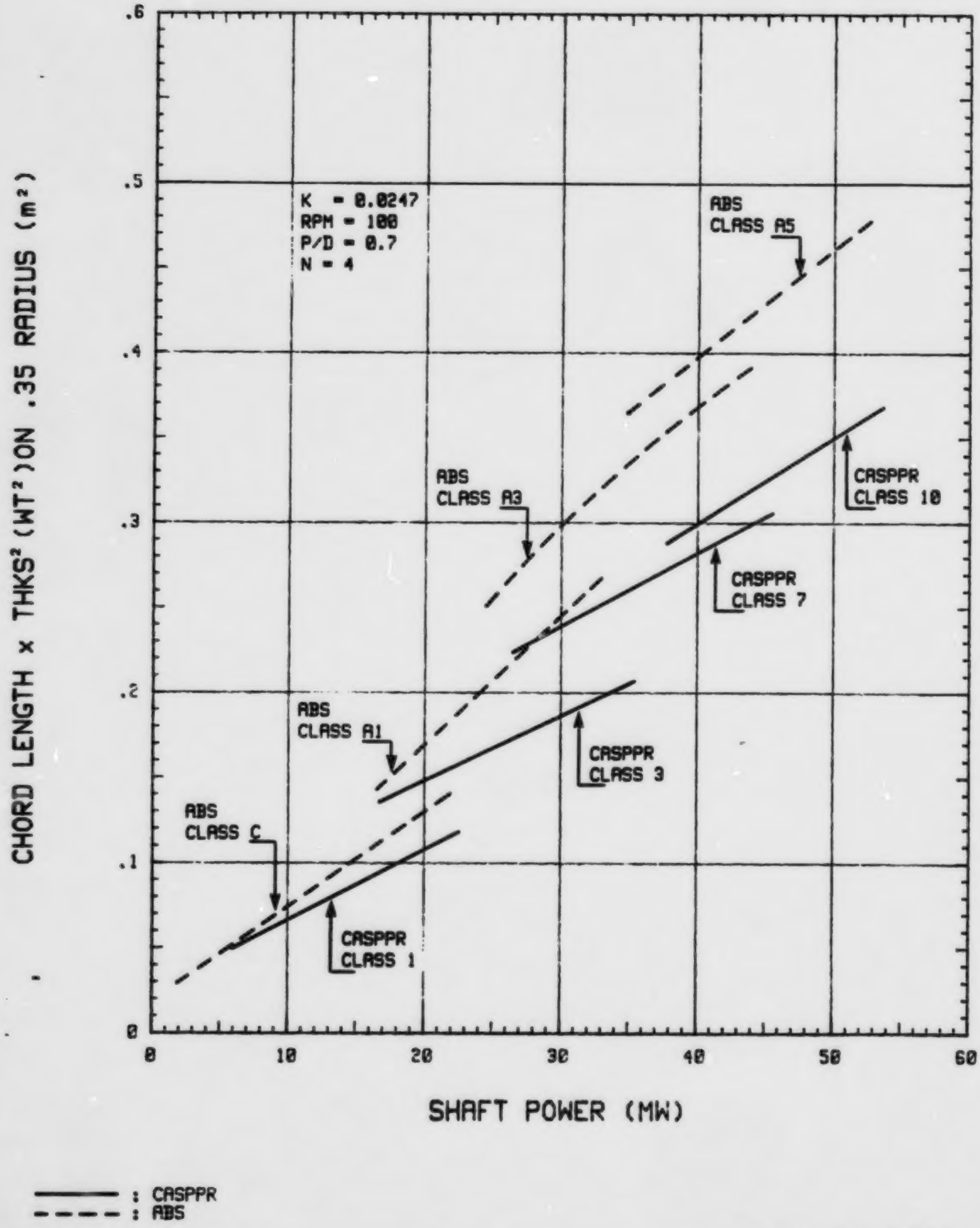


FIGURE 5.4.7

BLADE STRENGTH REQUIREMENT VS SHAFT POWER



It has been generally accepted that the sectional scantlings for ducted propellers can be lower than those for the non-ducted propellers, as the severity of interaction with ice is substantially reduced by the presence of the nozzle.

5.4.2.2 Selection of Material

In addition to the requirements for general marine propellers, the material used for propeller blades of ice class vessels must have high proof stress and impact resistance quality. Meanwhile, a small difference between the tensile strength and the yield strength of the blade material is preferred to prevent any damage to the hub or shafting systems.

Stainless steel and bronze are the common materials today for ice-strengthened propeller blades. Most ice going CP propellers of bronze material are operating in nozzles whilst most stainless steel CP propellers in ice service are open propellers. Stainless steel generally has a higher erosion resistance, and a higher ultimate strength and yield strength than bronze material, thus allowing a more slender and efficient blade profile. Table 5.4.1 shows a evaluation on a number of bronze and stainless steel materials for ice strengthened propellers based upon the materials' strengths, anti-corrosion/erosion and other engineering properties (Imamure, 1982).

The selection of propeller materials for recent Canadian icebreaking ships is illustrated below:

Ship	Propeller Material
Arctic	Cunial Bronze
Kigoriak	Cunial Bronze
Robert LeMeur	Cunial Bronze
Terry Fox	Cunial Bronze
Radisson	Cunial Bronze
Arctic Ivik	Cunial Bronze
Ikaluk	Cunial Bronze
Polar Star	Stainless Steel

*ND - No Data

5.4.2.3 Influence of Nozzles

- Propeller nozzles have the advantage of increasing the thrust over a range of ship speed. For icebreaking vessels, the nozzle also offers a very effective means of protection of the propeller, and may reduce the strength requirements for propeller blades.

TABLE 5.4.1

Mechanical Properties Of Copper Alloy Castings

		High Mn Br	Mn-Br	Nl-A1-Br
Tensile Strength	kgf/mm^1	≧66	≧50	≧66
0.2% Proof Stress	kgf/mm^1	≧26	≧20	≧26
Elongation	%	≧15	≧20	≧15
Impact Value	kgf.m/cm^1	≧33	≧ 4	≧35
Fatigue Strength in Seawater (2 x 10')	kgf/mm^1	≧16	≧10	≧17

Mechanical Properties Of Stainless Steel Castings

		Grade 13CR (A)	Grade 13Cr (B)	Grade 13Cr (C)	Grade 16 Cr
Tensile Strength	kgf/mm^1	≧55	≧90	≧80	≧90
0.2% Proof Stress	kgf/mm^1	≧35	≧45	≧60	≧30
Elongation	%	≧18	≧10	≧15	≧10
Impact Value -5^0)	kgf.m/cm^1	≧ 2	≧ 3	≧ 5	≧ 5
Fatigue Strength in Seawater (2 x 10')	kgf/mm^1	-	>40 (Electric cathode protection)	≧24	≧24

TABLE 5.4.1 (cont'd)

Evaluation On Propeller Materials

NO.	CHARACTERISTIC	WEIGHT	HIGH Mn-Br	Mn-Br	Ni-Al-Br	GRADE 13Cr(B)	GRADE 13Cr(C)	GRADE 18Cr
1	Strength	5	4	3	4	5	5	5
2	Toughness	3	5	4	5	2	3	2
3	Fatigue Strength	5	3	2	4	5	5	5
4	Anti-corrosion Property	3	2	1	2	4	4	5
5	Anti-erosion Property	5	2	3	3	5	5	5
6	Specific Gravity	2	5	3	5	4	4	4
7	Repairability	4	4	5	5	3	3	4
8	Workability	3	5	5	5	3	4	4
9	Cost	4	5	5	4	3	3	3
10	0.2% Proof Stress	5	2	1	2	4	5	2
11	Tensile Strength - Proof Stress	5	3	3	3	4	5	2
12	Impact Value	5	3	4	3	5	5	5
	EVALUATION		167	156	177	199	215	189

Note: The evaluation is done by the total of each product of the weight for the characteristic by the score to the material.

As can be seen from Figure 5.4.1 that there are few icebreaking ships with nozzles. Those Canadian ships, such as Arctic and Kigoriak, which are equipped with nozzles have experienced successful operations with very few problems. Those shallow draft vessels which operate in the Beaufort Sea have occasionally experienced clogging of the nozzles when in very thick ice or in rafted rubbled or ridged conditions. Notwithstanding this, nozzles are being considered for some of the future high powered ships.

5.4.3 Shafting and Shaftline Components

The components of the power transmission system which lie between the propeller(s) and the motors or gearboxes are critical to the propulsion system's reliability. It is these components which may be exposed to problems due to increasing propulsion power, although a growing body of experience is now available to guide the designer. The following discussion illustrates each component, the experience which is available and the conclusions which may be drawn.

5.4.3.1 Shafting

For very large Arctic class ships, high power and high torque will be required, resulting in very large diameter propeller shafts. The largest marine propeller shafts are fitted to a series of Seatrain tankers. These shafts are 1473 mm diameter and are fitted with 89 ton propellers driven through gearing at 101 RPM by 37 MW geared steam turbines. These shafts weigh about 160 tons. The maximum size of shaft which can be forged is based upon the maximum ladle weight which is presently limited to about 200 tons. This suggests that, depending upon length, a shaft diameter of about 1.6 metres may be the present maximum.

The diameter and materials of the propeller shaft of several icebreaking ships is identified in the following table.

Ship	**Shaft Power (MW)**	**Propeller Shaft**	
		Diameter (mm)	**Material Yield Strength (MPa)**
Arctic	11.08	610	215
Kigoriak	13.05	627	324
Terry Fox	8.65	775	300
Radisson	5.5	610	215
Polar Star	15	380	314
SA 15s	15.4	980	300
Polar Stern	7.34	380	ND

There have been various methods proposed to calculate the diameter of shafting. All methods are similar and are based upon blade section modulus and the ratio of UTS of the propeller blade material and the yield strength of the shaft material. The intention is that the propeller blades and shafting be designed on the 'pyramid of strength' basis and that the propeller blade should fail before the shafting.

The rules for propellers of the classification societies and CASPPR are similar and are based upon the Finnish-Swedish Ice Rules. The diameter of the shafting is calculated from the basic form:

$$\text{Shaft Diameter} = \text{Constant} \times (R \times WT^2)^{1/3}$$

Where R = Ratio of Blade UTS to shaft yield strength
WT^2 = Blade section modulus, calculated from a hydrodynamic torque plus ice torque.

Sample calculations demonstrate that the open water rule requirement for blade section modulus is more severe for propellers above about 20 MW regardless of ice class and ice torque factors. Therefore for high power ships, the blade section modulus must be calculated from first principles. It is, however, reasonable to expect that with an increase of hydro-dynamic torque, ice torque, as a percentage, would tend to decrease.

In the most recent proposals of American Bureau of Shipping, the blade section modulus calculation is adjusted by a multiplier to the hydro-dynamic torque term of their formula. For propellers above 30 MW, a multiplier of 2 is applied to the torque term. This has the effect of increasing the shaft diameter by about 26% (Imamura, 1982).

In the Swedish-Finnish Ice Rule formula, to calculate propeller shaft diameter, only torque is considered. Bending stresses are included indirectly by inclusion of the blade section modulus in the formulas. In the formula proposed by Ignatjev, a modifier to reflect the propeller over-hang is included. It is probable that for large propellers, the over-hung weight of the propeller and the reverse bending stresses induced in the shafting may be sufficiently high to warrant including directly as a parameter in the method to calculate shaft diameter. It is improbable that any specific allowance is required to take into account torsional vibrations as the allowance for over-torques will provide a sufficiently high factor of safety for this purpose (Sasaki, 1979).

In general, shafts are made from forged carbon steel, although low alloy steel forgings are also used. In the case of icebreakers with oversized shafts, considerable weight saving can be achieved by using the higher strength of low alloy steel and, in the case of the SHIRASE, over 100 tons were saved between three shafts (Sasaki, 1979).

The most critical aspect of shafting is the alignment in the bearings. It is misalignment of the shafting which is responsible for more forced outages of large vessels than any other reason (Hill, 1980). Problems of alignment arise from:

- changes of relative bearing position due to changes in draft which causes hull deflections.

- eccentric thrust on the propeller which introduces bending moments in the shafting.

- insufficient radial and axial bearing flexibility. As an example, the average stiffness for bearings in 15-35 MW propulsion installations are:

  Axial Bearings : 2 - 3 MN/mm
  Radial Bearings: 2.4 - 4 MN/mm

  This compares very well with the bearing stiffness measured in the USCG POLAR STAR and POLAR SEA.

- changes in the height of bearings, gearcase or the engine due to expansion as the machinery heats up or due to lifting of the machinery by expansion of the understructure because of tank heating.

In an Arctic class ship the ratio of shaft line stiffness and bearing stiffness is high due to the larger diameter shafting. This unfavourable ratio for ships with the engines positioned far aft will create a very stiff system and make alignment more difficult. Additionally, the mean thrust of an Arctic ship will be larger than an equivalent open water vessel and thrust variations of up to 3 times the design thrust can be expected due to ice loads. If excitation of axial resonant vibrations of the shafting is to be avoided, the stiffness of the thrust (axial) bearing is of vital importance. Severe problems due to the excitation of shaft line axial resonant frequencies have been experienced by the USCG icebreakers POLAR STAR and POLAR SEA.

5.4.3.2 Shaft Couplings

Shaft couplings are commonly of two types:

- flanged and either forged integral with the shaft or welded, shrunk or keyed to the shaft.

- muff type of the oil injection SKF type.

For fixed pitch propellers the all flanged type of shafting with shaft flanges forged integral is the most common system. The propeller is fitted to the tailshaft by nut and cone. The propeller is sometimes keyed to the shaft but recently the keyless system is becoming more common.

The torque which can be transmitted by flanged couplings depends upon the clamping force which can be applied by the bolts. For very high torques large diameter flanges with double rows of bolts may be necessary. To achieve the required flange diameter for large diameter shafting it may be necessary to weld the coupling flange to the shaft.

Where the propeller is bolted to the shaft, as with the controllable pitch propeller, an external flange on the shaft is provided and the internal coupling is of the oil injection muff type permitting the tailshaft to be withdrawn externally. The advantage of the muff type oil injection coupling is the ease with which it may be fitted. Its disadvantage is its large weight and, while it can transmit high torque, its propensity to slip under simultaneous high torque, high axial loads and bending which will occur during full power ice milling. Therefore, when this coupling is specified, all of the conditions which the coupling must meet must be fully described. There have been no reported incidents of couplings of ice class ships failing due to ice loads.

5.4.3.3 Shaft Seals

There are three types of tailshaft sealing systems which are in common use:

- Packed glands using synthetic or natural fibres
- Radial lip seals
- Axial face seals

Packed glands were the traditional type of seal used for tailshafts but are rarely fitted to modern ships. These glands were fitted to ships with relatively small shafts and lignum vitae or other water lubricated tailshaft bearings and are not suitable for oil lubricated tailshaft bearings.

The most commonly fitted sealing system for propeller shaft bearings are radial lip seals. This seal has been used extensively in open water and Arctic class ships and has a proven record. The seal is particularly sensitive to shaft surface finish, rubbing speed, shaft eccentricity, shaft vibration and pressure difference across the seal face. For deeply submerged propellers, special designs are necessary. The rubbing speed between the shaft and seal should be maintained at less than about 6 m/sec although higher speeds, up to 8 m/sec, have proven efficient on test rigs. The limit of rubbing speed is intended to contain the high lip surface temperature (McIlvean, 1976).

In general, lip seals are suitable for Arctic class ship with moderately sized shafts, up to about 1200 mm in diameter, and small aft stern bush bearing clearances, i.e. to limit the magnitude of the shaft movement in the seals. It is improbable on the basis of open water experience that these seals will be suitable for large diameter shafts which will be required for the larger and higher ice class ships.

The face seal or axial seal tends to be more complicated and more expensive than the lip seal but is able to accommodate relatively large axial and radial movements of the shaft without loss of seal efficiency. Axial seals also permit operation with far higher seal pressure differential, i.e. they are more suitable for deep draft vessels. Face seals for shafts up to 1600 mm diameter have already been tested and there appears to be few technical limits to extend the seal diameter to the largest sizes which could be accommodated on a ship. Face seals are used on the Canadian 'R' class icebreakers and on many of the Russian icebreaker and ice class ships.

5.4.3.4 Sterntube and Intermediate Shaft Bearings

A number of factors influence the performance of bearings, such as material, lubricant viscosity, vibration, initial alignment, changes of alignment in service and dynamic loads. The operational requirements are particularly difficult to quantify for any vessel and are more difficult for ice class ships due to the influence of the ice on the propeller and hull. The change of attitude of the shaft in the bearing due to ice and hydrodynamic forces acting on the propeller, coupled with changes of the bearing line due to deflections of the hull, can result in the bearing operating in a misaligned condition.

The sterntube bearing is the most difficult bearing in the ship to design due to its imperfect operating condition. In the past lignum vitae was the preferred material, using water as a lubricant. In this type of bearing hydrodynamic lubrication could not be achieved and hence the bearing had to be long, at least four times shaft diameter, to carry the load, and was routinely replaced at frequent intervals. Due to the high maintenance requirements, power loss in the bearing and its unsuitability in carrying the propeller and shaft loads of modern ships, other types of bearings and bearing materials are now in use.

In vessels which require water lubricated bearings, various rubber compounds are used either in the form of staves or continuous bushes with axial grooves. Alternatively, plastic materials are used such as tufnol. Recently, rubber stave bearings have been used in icebreakers in the Canadian Coast Guard Fleet and in the US Coast Guard vessels including POLAR STAR and POLAR SEA. In the case of the POLAR STAR and POLAR SEA, the rubber staves have been used successfully to replace the original tufnol type material which was requiring excessive maintenance (MER 1985). Rubber materials are also used in the USSR SA 15 Arctic class cargo vessels and no problems have been reported.

Although rubber bearings are superior to lignum vitae and tufnol, as rubber will naturally deform to spread the load, the load carrying capacity is low when compared to oil lubricated bearings, therefore the bearing must be excessively long or of a larger diameter to support the load. Due to the problems of shaft curvature in the bearings brought about by the propeller overhung weight, there is a limit in the use of water lubricator bearings for high powered vessels.

The most commonly used bearings for sterntube and intermediate shafts are 'white metal lined', while more recently 'phenolic resin' has gained favour for the sterntube bushes. These bearings use oil as a lubricant, achieve hydrodynamic lubrication, have a specific load bearing capacity of 0.8

MPa (120 psi), and can be used with an L/D ratio of 1.5. These bearings are used on the largest ships in service today and on many privately owned Arctic class ships in Canada.

The experience in Canada of white metal stern tube bearing bushes in Arctic ships has been good. There have to date been no serious problems although the sample size is small. White metal as a bearing material has advantages but also some quite serious disadvantages. The principal advantages are that it is easily worked and is self-healing in the event of an overload. However, these bearings are prone to failure in misaligned conditions, which can easily occur in the aft tailshaft bearing, are liable to fatigue, and have poor performance under edge loaded conditions (Hill, 1980).

These problems prompted the development of the 'phenolic' and 'cryselic' resin bearings. While these bearings have solved some of the problems of white metal bearings, such as greater resistance to damage under edge loaded conditions, more tolerance to overloading and more resistant to fatigue, they have introduced other problems. The principal problems with the plastic bearings is that under overload conditions the bearings can become extremely hot and in some instances have resulted in a bent tailshaft. The material has a propensity to creep despite early test results to the contrary. This means that extreme care must be taken to ensure there is sufficient clearance in the bearing. From the ship operator's viewpoint, the largest single advantage of the plastic type bearings is the possibility of operating with water lubrication at slow speed should the oil seal fail. Many vessels have managed to complete their voyage using water lubricated resin bearings after a seal failure.

The sterntube bearing materials for several Canadian, USA, and USSR icebreaking ships are identified in the following Table.

Ship	**Sterntube Bearing Material**
Arctic	white metal (oil lub)
Kigoriak	cryselic resin (oil lub)
Terry Fox	cryselic resin (oil lub)
Radisson	rubber (fresh water lub)
Polar Star	rubber (salt water lub)
SA 15s	rubber (fresh water lub)

- Intermediate shaft bearings must be 'full bearings', ie. the top and bottom halves must be similar because, in an extreme case of a transient load on the propeller, the bearing could become top loaded instantaneously. The use of tilting pad type of bearings is favourable for the influence of bending moments, although in small vessels with a relatively low ratio of shafting stiffness to hull stiffness the advantage is small.

5.4.3.5 Thrust Bearings

The conventional thrust bearing is of the 'tilting pad' type and is fitted to all modern vessels. This type of bearing replaced the 'multi-collar' type which is no longer in use.

The tilting pad type of thrust bearing is successfully used in all applications and has proved to be reliable. In high power ships there is a tendency now not to include in the thrust bearing pedestal a journal bearing. This is because the thrust bearing and pedestal deflect under load causing a change in shaft alignment. It is also becoming common practice, for Arctic class ships, to install thrust bearings external to engines, if arranged for direct drive, and external to the gearbox. This is most important where large thrusts are expected, to prevent the load on the thrust bearing being transmitted to the structure of the engine or gearing enclosure.

The thrust block location on several icebreaking ships is identified in the following Table.

Ship	Shaft Power (MW)	Location Of The Thrust Block
Arctic	11.08	In the Gearbox
Kigoriak	13.05	In the Gearbox
Terry Fox	8.65	In the Gearbox
Polar Star	15.00	On the Propeller Shaft
S.A. 15s	15.40	On the Propeller Shaft
Polar Stern	7.34	On the Propeller Shaft

The major problem with thrust bearings, is related to the maximum achieveable stiffness of the thrust bearing foundation. In conventional ships, thrust bearing foundation stiffness is of the order 200-400 tonnes/mm and to achieve higher stiffness will require an increase in the scantlings of the ships longitudinal structure.

The tilting of the thrust block under load due to the cantilever affect must also be considered and the thrust block for very large Arctic vessel may have to be attached to the vessel structure at top and bottom. The maximum stiffness required for thrust bearings is unknown, as this will depend on the propulsion systems sensitivity to axial movements. Geared installations are particularly sensitive to changes of alignment, both radially and axially, and, if the movement of the thrust block under steady state, and transient loads cannot be reduced to a level which is acceptable to the system, a flexible coupling may be required between the thrust shaft and the systems to be isolated. The availability of a coupling which is simultaneously axially and radially compliant, under full load high torque and thrust conditions, is presently uncertain.

5.4.3.6 Special Bearings

The principal difficulty of designing a bearing system for present Arctic ships is related to the loading on the shafting system due to ice interference with the hull and propeller and the effect of that interference on axial and radial bearing raction and shaft alignment.

To compensate for the variable loads and variable attitude of the shaft in the aft stern bush or bearing, the use of a self-aligning stern bush and self- aligning zero clearance bearings, such as roller and ball bearings, have been considered. The purpose of the self-aligning feature is only to allow the bearing to follow the shaft during changes of attitude and slope, thus maintaining an even load over the projected area of the bearing. The bush does not act in any way to compensate for changes of bearing reaction. In practice, self-aligning bearings using spherical housings have not worked well. They were fitted to the Doxford slow speed diesel engines and were found to seize under load. The electric power generating industry had similar experiences where it was common practice to use this type of bearings in the turbines. All experience suggests that the bearings fail to slide in the spherical housing due to difficulty of lubrication of the spherical sliding surfaces and fretting corrosion of those surfaces. For use as an aft stern bush, all of these problems must be addressed together with that of manufacture of the system in very large sizes.

The use of hydrostatic bearings both in the plain form and combined with spherical housings have been considered for use in the aft stern bush and, for very large system, for the lineshaft intermediate bearings. Hydrostatic lubrication is difficult to maintain unless the axes of the shaft and journal are parallel. This system is independent of surface velocity of the shaft to create an oil film and is particularly suitable for slow speed shafts and heavy shafts when wear may be high during start-up. The use of hydrostatic lubrication is common with large turbines of power station when this system is used during barring and during start-up. This system can be applied to the very heavy propeller shafting systems large Arctic ships (Mourelatos, 1985).

The anti-friction group of bearings include all bearings where the load is transferred through rolling elements rather than sliding surfaces (ie. ball, roller and needle bearings). These bearings have been fitted in the 1970's by the SKF Company on the shafting systems of a series of ships. These bearings did not solve the sterntube bearing problems in large ships as was expected and are more costly than journal bearings. One of the problems was to provide the required load at all times to ensure that rolling contact and hence lubrication were maintained. In marine shafting practice, with the fluctuating loads caused by the propeller, skidding of the elements may occur which leads to flats on the elements and damage to the track. There is very little experience of these bearings in marine shafting application although they may be suitable, after development, for use in the very largest of ships.

5.4.4 Mechanical Transmission Components

The most efficient means of supplying power to the propeller is by directly coupling the propeller with shafting to the output of the primemover. The only losses incurred with this system are due to the propeller shaft bearings. However, only slow speed diesel engines and steam reciprocating engines have a sufficiently low engine speed to permit them to be directly connected to a propeller. All other engines, such as the medium speed diesel and steam and gas turbines, have an output speed which is too high to obtain the best propeller efficiency. For direct drive systems these engines are connected to the propeller with a speed reducing transmission system.

As shown on Figure 5.4.1, since 1966, many icebreakers and ice class cargo ships have been fitted with direct drive propulsion systems and gears. All of these vessels are driven by one or more medium speed engines and single reduction gears, except for the Soviet LASH vessel which is driven by a steam turbine. These vessels are also fitted with controllable pitch propellers, some with the propellers in nozzles.

The recently delivered USSR SA15 cargo ships have fluid couplings fitted to the gearboxes, which limits the overload torque. Other ships are fitted with oversized flywheels on the shafting to smooth out transient ice torques and it is virtually standard practice for all ships fitted with diesel engines to be arranged to shed propeller pitch when the engine fuel rack is at a maximum to prevent engine stall. All medium speed engines are connected to the gears by means of a clutch. For the vessels with fluid couplings, the coupling can also double as a clutch.

The components of mechanical transmission systems are critical to the successful operation of the vessel and these components must be critically evaluated to ensure suitability for the loads which are envisaged. Each component is discussed in the following text.

5.4.4.1 Gears

Vessels which operate in the Arctic and are fitted with gears are of relatively low power and the design and manufacture of the gear sets are well within the experience of manufacturers. The largest gearboxes fitted to an icebreaker are the single input double reduction gears on the icebreakers POLAR STAR and POLAR SEA. These ships are powered by a combined gas turbine and diesel electric system, with each of the three gas turbines driving a double reduction gear box. The gas turbines are each rated at about 18.7 MW. The overload rating of the gears is not known, but the gas turbines under stall conditions can develop in excess of twice nominal torque and, unless protection is provided, the gears will have been so designed.

The largest gearboxes fitted to Arctic cargo ships are those on the USSR SA15s, rated at about 15 MW, with twin inputs, each of 7.5 MW. The engines are connected to the gears through two fluid couplings which permits full torque to be developed through the speed range of the propeller and limits ice loads to the engine. These gears are probably designed with an ice overload factor of 1.5.

There are many smaller gear sets fitted to Canadian vessels. The most interesting of these systems, on the Beaudrill vessels, have a large flywheel in the intermediate shaft aft of each gearbox. The flywheel has the effect of providing additional energy in the system to permit the system to ride through short transient overtorques with the minimum of speed loss and significantly reduces ice induced vibrations which might otherwise effect the gears (Motor Ship, Oct. 1983).

The largest marine gears, measured by torque capacity, have been constructed by Renk, West Germany. Triple input single reduction gears of 34 MW output, at about 110 RPM, have been built for container ships and are in service. The same company has constructed twin input gear sets rated at 25.6 and 85 RPM, with an overload factor of 1.5, for operation in ice. The bull wheel for this gear is 4.4 metres in diameter, through-hardened and weighs 31 tonnes. This gear is equivalent to an open water rating of over 40 MW at an output speed of 10[illegible] RPM, but has not entered service (The Naval Architect, Sept. 1983).

Gear sets have been made in many configurations, with either single or double helical cut gear teeth, and as single, double or triple reduction depending upon the required overall gear ratio. Generally, up to 20:1 gear ratio can be supplied from a single reduction external gear and up to 30:1 from internal gears (epicyclic type). For turbines, double and triple reduction gears are required whereas single reduction gears are sufficient for medium speed diesel installations.

The choice between single and double helical designs is complex (Sigg, 1972). With few exceptions, very high power, high torque gears supplied for ship propulsion service are external double helical gears. These are quiet running, are self-compensating for thrust, and require no internal thrust bearings. The single helical gears are technically equal to the double helical gears but require internal thrust bearings and are more commonly used for the low power marine installations.

The choice of materials for gears is an evolving science. All gear materials are hardened to some degree to provide tooth surface durability, although some gears are very much harder than others, ie. the case hardened or carburised gears, and these are termed "hard" gears.

The hardness of the gear teeth determines the load carrying capability per unit area, often termed the K factor, and limits the size of gears. The introduction of high power medium speed diesel engines requires the use of gears with the highest possible K factor to keep the size of the gears as small as possible. The largest diameter of bull wheel that can be case-hardened in the ovens presently available is 3.3 metres. High power gears, recently delivered, which exceeded this capacity, used 'through-hardening' of the bull wheel. Through-hardened gears are not as hard as case-hardened and are therefore larger (lower K factor).

As an alternative to an increase of diameter of the bull wheel, the length of the gear teeth can be increased. This gives rise to very severe problems of alignment due not only to the maintenance of manufacturing tolerances during machining the blank but tojudging the helix angle correction allowance to be made to compensate for pinion deflection and torque wind-up of the pinion when under load. The length to diameter ratio of pinions is at present limited to about 2.5; for high ratios very high corrections would be required (Saunder-Davies, 1980; Broersma, 1961). While much can be calculated, the allowances of helix angle correction, tip relief, etc. are matters of judgement and depend to a large extent upon the experience of the manufacturers.

There is no theoretical limitation of the size and output torque for which a gear set can be built. However, in the design of gears the allowances which can be made to offset pinion and gear tooth deflection under load and the effects of soft foundations on the alignment of the gears is an art and not a science. Development of gears has generally been good, although destructive pitting of the teeth of large soft gears of 20-30 MW fitted to VLCC and ULCC tankers driven by steam turbines, is more common than published literature might suggest (Saunder-Davies, 1980). Similarly single reduction hardened gears fitted to diesel engines have been prone to damage when operating at off-design conditions (Volcy, 1977; Saunder-Davies, 1980). Experience suggests that gear development can safely take place by increases of the maximum size by small increments, but there is a danger in increasing the size in large steps.

The problem to be overcome when manufacturing very large gears, is to maintain the very close tolerances of gear cutting when handling large diameter and heavy gear blanks. In operation, the problem is to maintain internal alignment between the gears when the gear case is mounted on the flexible foundation provided by the ship's hull. Maintaining alignment between gear teeth would be made easier if the load was constant. Unfortunately, in very large icebreaking ships the load is rarely constant. However, developments in gear case design have been made to overcome past problems of gear misalignment due to foundation distortion (Pinnekamp, 1974; Degeorge, 1982).

Manufacturers have not yet been required to address the problem of large axial movements of the propeller shaft due to the variations of thrust. While axial movements of the shafting occurs on all vessels, where these variations are of large magnitude the thrust bearing must be mounted external to the gears. The full load thrust for very large vessels and the relationship of that thrust to the achievable axial stiffness of the structure of the ship may cause problems for gear manufacturers. Fore warning of this type of problem has been given by experiences of axial vibration problems of the USCG icebreakers POLAR STAR and POLAR SEA. In these vessels there appeared to be a limit of about 300 tonnes/mm of axial stiffness. For vessels designed for about 400 tonnes full load thrust per shaft and an overload rating of up to three times this figure as vibratory thrust, very large shaft movements will take place unless very large thrust bearing seating axial stiffness is obtainable. If this stiffness is unobtainable, means will be required to limit the effects of the shaft movements on the gears (Vassilopoulos, 1980).

As an illustration of the problem of the construction of large gears for Arctic class ships, the bull wheel of a large Arctic ship was calculated by manufacturers to weigh about 80 tonnes. The gear was to be a double reduction twin input articulated gear, with divided torque paths rated at 56 MW at 80 RPM and an overload factor of 2. While the gear set could be designed, there was no previous experience of the manufacture of a gear blank of this size and it was not known whether there was the capacity in industry to build the blank. Gear manufacturers did not have the craneage in their factories to handle a work piece of this size, and the foundations of the gear cutting machines were not designed for this weight, although the machines had the capacity. The gear set could not be tested due to the very large normal load torque and a rated torque of twice normal. There was an unresolved debate as to whether the helix angle correction should be applied for the twice nominal torque condition, the full load condition or an intermediate value. Similarly it was not known whether the maximum overload condition should be designed on the basis of yield strength or endurance strength. Neither of these questions are simple to resolve.

No known serious problem has been experienced with the gears of any of the existing ice class ships even although many of the ships are fitted with the thrust block internally in the gear case. There has been no report of pitting of the gear teeth, which often is the first indication of impending problems. Unresolved problems with the gears of POLAR STAR and POLAR SEA have been reported, although it is presumed the problems are not sufficiently serious to withdraw the ships from service

It would seem that gears can be safely fitted to ice class ships and the evidence suggests they will provide reliable service. Present experience of gears extends only to about 20 - 25 MW per input shaft and about 30 MW per output shaft for any ship. To extend that rating significantly in one step would present problems not only of gear cutting and design but also of maintaining the internal alignment of the gears when in service in the ship. Manufacturers have made large advances in gear case design and the mounting of gear cases in ships to minimise alignment problems due to gear case distortion (Pinnekamp, 1974) and these advances will be applicable to large ice class ships.

5.4.4.2 Clutches

The use of friction type clutches in the propulsion systems of ships is limited to the connection of medium speed engines to gearboxes. These clutches permit the engine to be started under no load and then connected to the propeller system. Clutches have a secondary value for icebreaking ships as they permit the engine to be automatically disconnected from the propeller under stall conditions and, under certain conditions, can be permitted to slip.

Friction clutches for marine use are designed as either wet or dry plate types and are actuated either by compressed air or hydraulically. These clutches have been used extensively in existing ice class ships which have medium speed diesel engines and gears. For large installations the wet plate clutch using sintered bronze clutch plates are generally preferred. While these clutches may be permitted to slip for a very short time, the very large heat produced when slipping must be dissipated by the oil coolers, and clutch plate distortion, due to the very high local temperatures, may occur.

Manufacturers claim that these clutches can be produced to any size required by simply increasing the number of plates and the clamping force. The friction plate type of clutch has been proposed for ice class ships as protection devices for the engine to prevent stall by permitting the clutches to slip during overtorque. As far as is known they have not yet been used in this way.

Warships often use the self-synchronising type clutches to connect gas turbines and steam turbines to gear drives. These clutches are very useful under certain circumstances but are mechanically complicated. There are several different types of these clutches, all of which permit the primemover to run up to speed independently and self-engage in a stepless manner once the speed of the input and output elements match. Similarly the couplings can be made to automatically disengage under reverse torque, thus permitting engines to be added or removed from a system without stopping the whole unit.

Self-synchronising clutches are not commonly used by commercial ships, but were considered for the COGAS system of the Arctic Pilot Project LNG carriers, so as to couple the gas turbines and steam turbines to the gearboxes. One application would be to couple the gas turbines of the USCG POLAR STAR and POLAR SEA to their gearboxes. However, dry plate clutches on the secondary pinions and manually engaged dental type couplings on the propeller shafting have been preferred in these ships (Finizio, 1974).

5.4.4.3 Fluid Couplings

The use of fluid couplings in ships is limited by size. Couplings are only available to transmit relatively low torques and must therefore be fitted to a high speed element in the system which is normally the output shaft of the engine. If a coupling is to be used in a torque limiting role, i.e. permitted to slip under over-torque conditions, very large hydraulic oil coolers must be fitted to dissipate the heat generated.

The torque ratio of a fluid coupling is 1:1 which means that the coupling does not aid the primemover in overcoming over-torques but does permit full engine torque to be applied at low propeller speed when the propeller is under stall conditions. There is a speed difference between the 'impeller' and the 'runner' which increases in proportion to the torque transmitted. The slip of the coupling at full load is about 3 percent. The coupling has zero torsional stiffness and therefore very effectively isolates the primemover from down stream disturbances. This type of coupling is used in the Soviet SA15s.

Figure 5.4.8 illustrates the torque ratio and efficiency of a typical torque converter. The principle of operation is similar to that of the fluid coupling except that a stationary element is introduced between the impeller and the runner. The maximum efficiency of the converter occurs at the design ratio of input to output shaft speed. The output torque of the coupling increases rapidly for lower output speeds, becoming five to six times the input torque at stall. The output torque decreases with increasing output speed and becomes zero at the runaway speed.

A variation of this type of coupling is the reversing coupling. By the insertion of blades between the runner and impeller the direction of the flow of the hydraulic fluid can be changed and cause the runner to reverse direction. This type of system is used for gas turbine driven warships but has very limited application to merchant ship use since controllable pitch propellers are preferred.

5.4.4.4 Electric and Powder Type Couplings

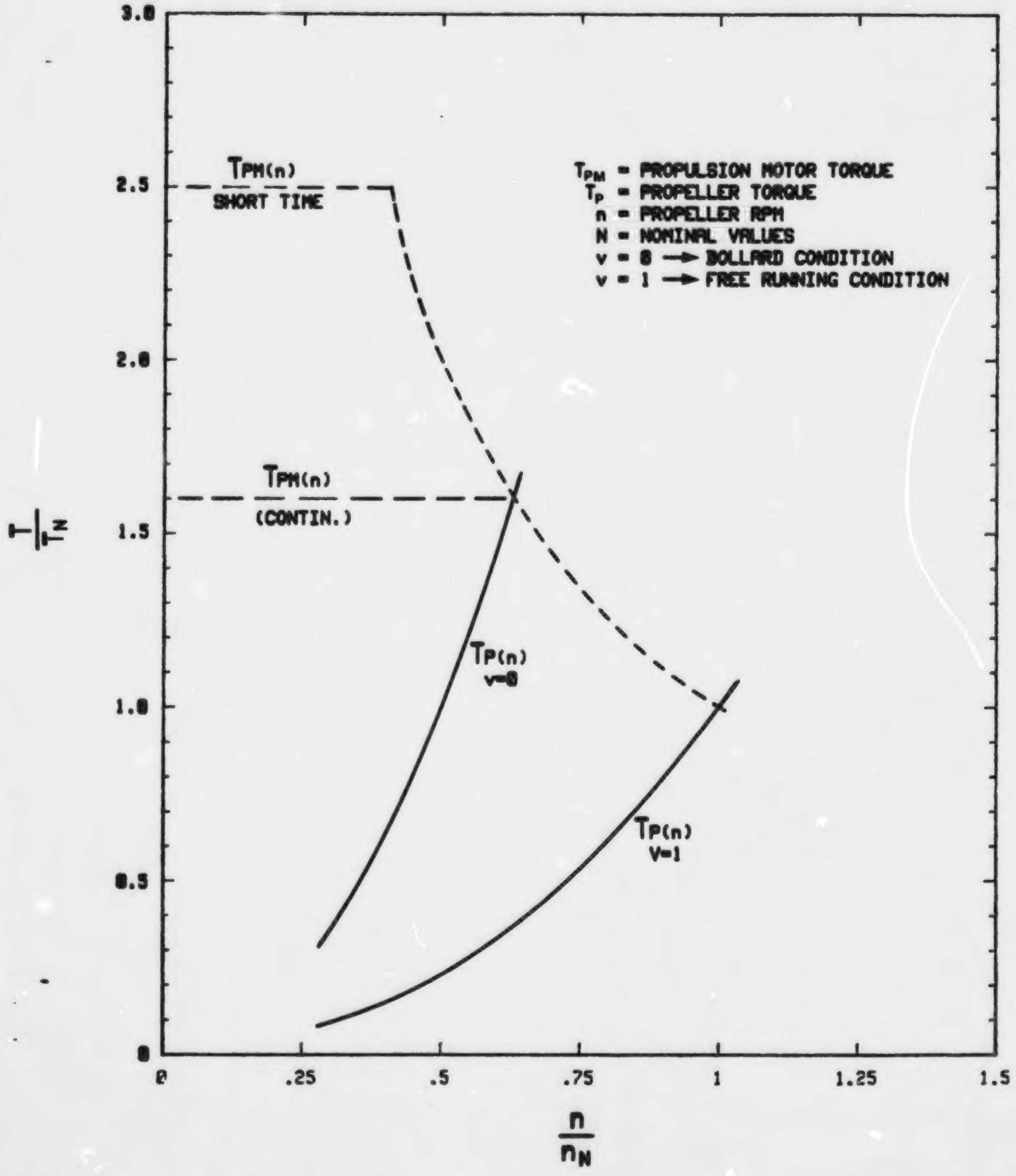
Electric couplings have similar advantages to a fluid coupling and in principle are similar to an induction motor. The coupling relies upon developing a torque by rotating a magnetic field around a squirrel cage winding. The couplings can be designed for very high torques at large slips and hence are similar in many respects to a fluid coupling. The efficiency of this coupling under normal operating conditions is about 97%.

The size of the couplings are usually up to about 3 MW and are fitted most often between a medium speed engine and a gearbox. As with fluid couplings they are torsionally compliant and reduce the effects of transient ice torques on the gears and engine. These couplings could be used in icebreakers, although there are no known ships fitted with electric couplings.

Powder type couplings are only fitted to very small, low power ships and as far as is known are not yet manufactured in sizes large enough for icebreaking ships. Powder couplings are of the electro-magnetic type and operate virtually slip free. If these couplings were made in sufficiently large sizes, they might be suitable for Arctic class ships.

FIGURE 5.4.0

TORQUE CHARACTERISTIC FOR A TORQUE CONVERTER



5.4.5 Electrical Transmission System

Electrical propulsion systems are available in four types which, in chronological order of their development, are DC-DC, AC-AC, AC-DC and most recently AC-FFC-AC. AC-AC systems were in use as long ago as 1920 and recently in the second world war (T2 tankers), but these systems were relatively unsophisticated and did not have the speed control and low speed torque characteristics of the most recent systems which employ semi-conductor technology (Harrington, 1980; Stiglitz, 1984).

Although there are technical differences between the AC and DC systems for modern ships, AC systems are preferred because they are lighter, smaller and more efficient. The use of AC motors in preference to DC overcome the problems of commutation, which made DC machines more expensive to maintain and has limited the size to below 15 MW (Greene, 1982).

There is the potential for significant development of high power electric motor and generator technology by the super critical motor and generator. This type of machine is under development in many countries and prototype machines are already in service ashore. In the United Kingdom a super-critical motor is under development for the Royal Navy to power a mine sweeper. If super critical electric machine technology can be successfully developed for marine propulsion, much smaller and lighter motors and generators will be possible and system efficiency will become competitive with geared systems although the cost will be greater (McCall, 1973; Appleton, 1978).

The advantages of electrical transmission systems over direct drive systems are that the characteristics of the drive can be exactly tailored to the mission profile of the ship. Also the total electrical power for the ship can be divided among a number of machines and distributed among a number of users as the requirement for power dictates. There are advantages to be gained by the flexibility of placement of the generators in the ship and, most importantly for ice class ships, the electrical system isolates the primemovers from over-torques due to ice loads on the propellers.

The disadvantages of electrical systems are the high cost, larger weight and space requirements, low transmission efficiency and high manning requirement when compared to direct drive systems.

5.4.5.1 DC-DC Systems

This system has been most commonly fitted to vessels with electrical propulsion systems. Most systems fitted to icebreakers have used medium speed diesel engines as primemovers although steam turbines have also been used. Due to limitations of the commutator, the speed of DC generators and motors must be less than 1000 RPM and, when turbines are used to drive the generators, reduction gears are used to reduce the size of the turbine and increase its efficiency (Harrington, 1980).

The power of DC machines is limited by the capacity of the commutator brushes to transmit current. At present a current density of 12-14A/cm^2 is considered the limit and 1000 V for a single motor armature (Greene, 1983; IEEE Rules). Most ship propulsion motors are shunt wound and arranged for separate excitation. The largest motors presently in service at sea, rated at about 10 MW, are fitted to the ARKTIKA Class of USSR icebreakers. The upper limit of present DC motors is about 15 MW due to commutation problems. DC motors might be manufactured in future to 30 MW using water cooled windings and metal graphite brushes, however, these machines would be very heavy. Large motors and generators are usually totally enclosed and air cooled. Speed control of the motors is by the Ward Leonard system.

The torque characteristic of the DC motor is a function of the ability of the motor to absorb the current without overheating. For an icebreaker application, high torque at low speed is a requirement and is the principal advantage of this system. The over-torque requirement is usually a short-term rather than continuous rating to minimise the cost and size of the motor.

The major advantages of the use of DC systems are their basic simplicity, ease of control, good torque characteristics and lower cost than other electrical system. The disadvantages of DC-DC systems are their high cost, weight and volume compared to mechanical systems, low transmission efficiency of about 85% and relatively high requirement for manpower for operating purposes.

5.4.5.2 AC-DC Systems

The AC-DC installation was developed to take advantage of the lower weight, lower cost and mechanical simplicity of AC generators with the simplicity, and precision of speed control of a DC motor.

The conversion of three phase AC to DC by the use of thyristors was introduced in the 1960's and was adopted by designers of marine electrical propulsion systems. The use of thyristor control or SCR (Silicon control rectifiers) permits the use of 3 phase generators which can be arranged to supply power to not only the propulsion motors but to ship service consumers at the same time; the conversion from AC to DC can be carried out with low losses. Furthermore, the regenerative power caused by braking the propeller can be totally or partially absorbed by other consumers connected to the generating system. It is this system which is now used in many icebreakers.

Speed control of the DC motor is by control of the motor excitation which is supplied by current from separate SCR. The thyristor converter allows a power flow in both directions so that reverse power generated by deceleration of the propeller can be fed into the system. The current, however, can only flow in one direction. There it is absorbed by other loads or the diesel generating sets. Consequently, in order to reverse the torque of the DC motor the direction of the magnetic flux has to be changed. For this purpose a reversible static converter is used.

5.4.5.3 AC-AC Systems

AC-AC systems have been extensively used in the past, principally during the shipbuilding boom in the second world war when the T2 series of AC-AC tankers was introduced by the United States. Early AC motors used for propulsion were of the induction type but these were replaced by synchronous motors with an induction motor winding for manoeuvring purposes. Control of these early machines was by frequency control through variation of the speed of the alternator.

There are three candidate designs for AC-AC propulsion systems for ships, all of which are based upon synchronous motors. The AC-AC system is the simplest and least expensive. With this system the motor speed is controlled by varying the speed of the primemover and thus the frequency. The alternating current acts in the same way as reduction gears. Although this system is probably the most economical system for open water ships, it is totally suitable for icebreaking ships. Ice interaction with the propeller may cause the motor and generator to fall out of synchronism when the propeller is subjected to large ice loads and starting may be difficult unless synchronous starting with a frequency converter is used.

The other disadvantage of AC-AC systems relate to low torque when starting, and the excitation of resonant vibrations when using a synchronous method. Resonant frequencies can be excited due to the torque excited as the rotating stator field passes the salient poles of the machine. The torque oscillates at a frequency from twice the supply frequency to zero in the speed range from 0-100% speed. This will also cause the shaft torque to oscillate during starting. Large motors have a natural frequency of vibration below 120 Hz and, consequently, resonance must be investigated. It has been reported that resonance at start-up can produce shaft torques between 6-8 times nominal.

Synchronous starting of one motor with a frequency converter is a possibility which could be used but is very expensive and does not provide any appreciable overtorque during starting. The current from the converter is only sufficient to overcome the load torque plus that required to accelerate the motor and connected system. This form of starting is smooth, as the converter increases the frequency steplessly from zero to synchronism which minimises stresses in the shafting, switchgear and supply network.

The AC-AC, full frequency control (FFC) or cyclo-converter system is the most suitable AC-AC system but is also the most expensive. Cyclo converters have been fitted to the latest Finnish icebreaker OTSO, 7.5 MW per shaft, and has been ordered on the TAIMYR class of icebreakers 15 MW per shaft for the USSR (MER 1986). By this means the motor can be controlled precisely and steplessly by a highly reliable static control system.

The principal advantages of the system are:

- Full torque available through the entire speed range to stall.
- No danger of loss of synchronism.
- Primemovers can be regulated to operate at their most economic speed provided a separate cyclo-converter is provided for auxiliary power requirements.
- Main generators can supply all auxiliary power requirements.
- Starting current does not exceed rated current.

The principal disadvantages are:

- High capital cost for the system.
- High volume and weight.
- Relatively poor overall efficiency of the transmission system, estimated at 90-92%.

AC-FFC-AC systems are technically superior to AC-DC and DC-DC systems due to their higher transmission system efficiency and their nearly indentical torque characteristics. There are no upper limits of the theoretical size of the alternators although motor dimensions and weight would influence the actual size of motor which could be fitted into a ship. Two 44 MW motors are presently being fitted to the liner QE II.

An intermediate system uses a reduced number of thyristors for starting (Straight AC-AC with frequency start) but this system does not completely overcome the problems of the straight AC-AC systems (Gregov, 1982) and is unlikely to be recommended.

5.4.6 Primemovers

The ideal primemover for an Arctic class ship would possess the following characteristics:

Reliability:	the engines should be of simple construction, have generous internal clearances, have few moving parts and be easy to maintain by the ships crew.
Flexibility:	the engines should be able to operate efficiently and indefinitely at any intermediate power. The fuel consumption characteristic should be flat through the power and speed range and there should be a rising or at least a flat stall torque characteristic.
Manoeuvrability:	the engines should be able to respond rapidly to orders to change power and speed with a minimum of operator participation.

Robustness: the engines should be resistant to the effects of the environment, in particular, to the ingestion of cold air, toshocks and vibrations transmitted through the foundations, and to torsional and axial disturbances transmitted through the shafting.

No primemover used for ship propulsion exhibits all of the above characteristics, although primemover characteristics can be modified by the use of suitable transmission systems. The prime movers which have been installed on existing icebreaking ships are shown on Figure 5.4.9, plotted as power per shaft and total power versus year of construction.

5.4.6.1 Gas Turbines - Aero

Experience of the use of Aero gas turbine engines in the Arctic is confined to two vessels; the USCG icebreakers POLAR STAR and POLAR SEA. These ships and are each fitted with three Pratt and Whitney FT4 aero-engine derivative gas turbines, each of which drive a controllable pitch propeller through a gearbox. The engines operate with diesel fuel and are only used for heavy icebreaking; medium speed diesel/electric power is used for cruising and light icebreaking.

The Baltic Sea ferry Finnjet, and a series of fast container ships, the EUROLINER Class, were fitted with these engines. The history of the Euroliner ships has been extensively documented in published literature (O'Hare, 1972) which records poor MTBO (Mean Time Between Overhauls) and very high fuel consumption. The engines in these vessels were eventually replaced with medium speed diesel engines. The history of the Finnjet is also one of high fuel consumption and fuel costs. The engines in this ship have been retained but on additional diesel electric propulsion system has been fitted for fair weather and off-season opertion.

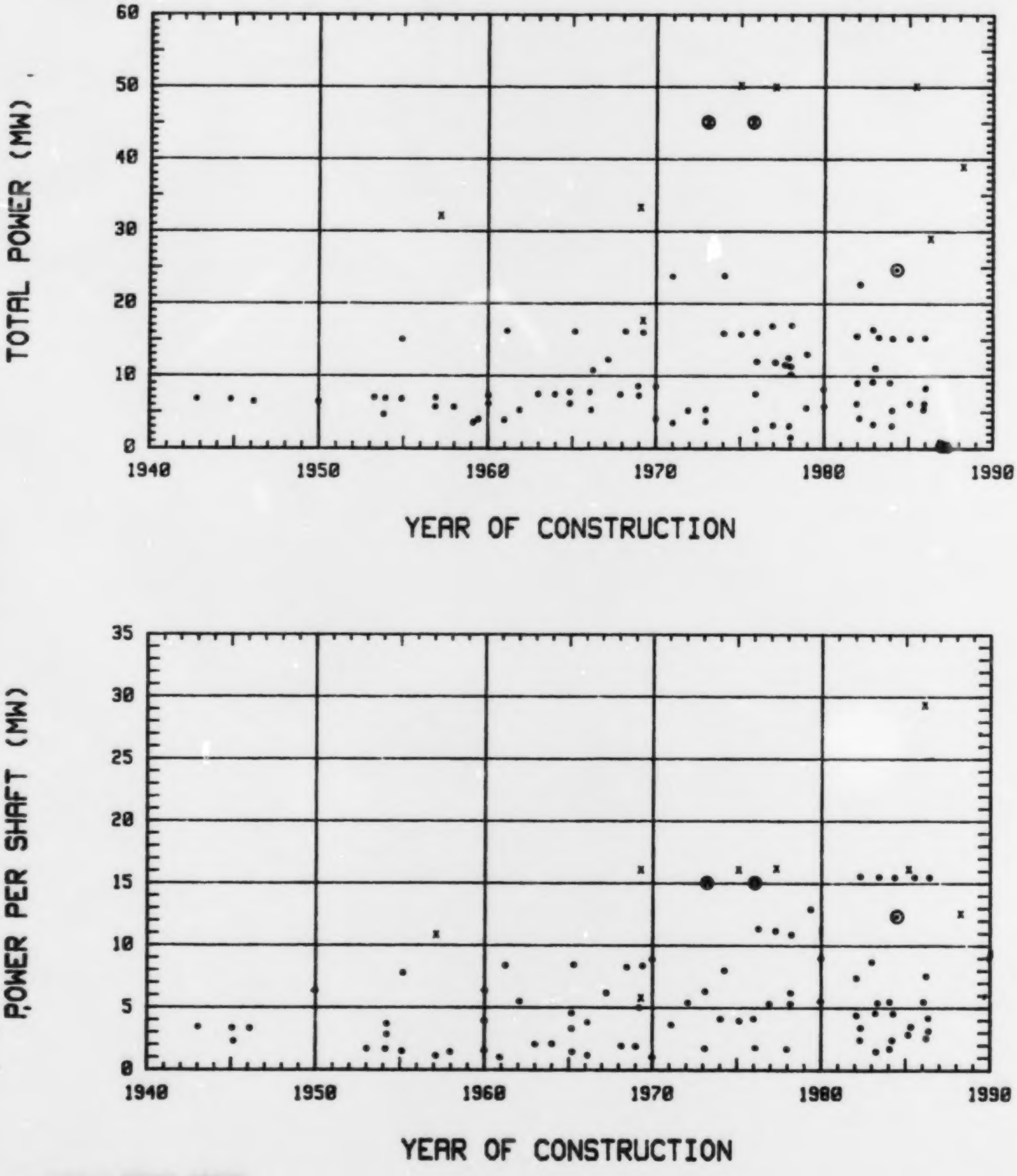
As the name suggests, aero-derivative gas turbines have been developed from engines which were originally designed to power aircraft. The marinised version of the aircraft engine has been modified to permit it to burn a slightly lower grade fuel than in aircraft and to resist hot corrosion due to the combined effects of sulphur and vanadium in the fuel and sodium in the seawater ingested with the combustion air.

The aero-derivative engines which are in use at sea and are presently available are in the power range 5 MW - 20 MW. The majority of these engines are manufactured by General Electric Co., USA and Rolls Royce, UK. There are other manufacturers but they do not occupy a large part of the market and produce small engines. Previously, Pratt and Whitney, USA manufactured marinised engines, and the FT4 engine was fitted to several ships. This engine was the most powerful of the aero-derivative engines available and rated up to about 30 MW.

Gas turbines are uni-directional engines and astern operation must be provided by the transmission system. Engines which are arranged to drive through an electrical system require no special provisions for astern

FIGURE 5.4.9

PRIME MOVERS INSTALLED ON ICEBREAKING SHIPS



operation. Engines which drive a propeller directly through gears are fitted with either a hydraulic reversing coupling (warship practice), or a controllable pitch propeller (commercial ship practice).

The engines have a rising torque characteristic under stall conditions and will generate up to 2.5 times full load torque at full stall. The manufacturers claim that gas turbines can be maintained at a complete stall for some minutes without damage.

The aero-derivative machines must be provided with a clean fuel and air supply if the engine is to be reliable. The fuel can be natural gas (methane) or distillate oil. Fuels with high sulphur or vanadium and combustion air containing even small quantities of sea water (sodium) will result in hot corrosion of the turbine blades and combustion cans. Efficient filters and demisters for the intake air are mandatory. Engines which operate with natural gas as a fuel and with a clean supply of combustion air increase the MTBO (mean time between overhauls) by up to three times.

The greatest advantages of gas turbines over other propulsion engines are the very high power to weight ratio, the compactness of the turbine installation and the low fitting out cost which is reflected by the lower overall capital cost of the ship. The greatest disadvantages are the very high fuel consumption, especially at off-design conditions, the cost of the fuel and the maintenance requirements.

Gas turbines may be suitable for ship propulsion in the Arctic if high power and a lack of space in the engineroom are the over-riding criteria. If natural gas is available as fuel at an economical price and if gas turbines can be combined with steam turbines in a COGAS system, these machines may prove to be an economical choice for the propulsion of ships which require very high power.

5.4.6.2 Gas Turbine - Industrial

The CCGS ice breaker Norman MacLeod Rodgers was fitted initially with two Westinghouse Model W21 industrial gas turbines, designed to operate with diesel fuel, each driving a DC generator in parallel with medium speed diesel driven generators. These gas turbines have been replaced by conventional medium speed diesel engines due to the high fuel cost of the gas turbines.

There has been very little reported on the performance of these engines. However, the replacement of the engines is consistent with the replacement of all industrial gas turbines installed on open water vessels due to a combination of high fuel consumption and high maintenance costs.

The industrial gas turbine was developed for land based stationary plant and is capable of burning low grade liquid fuel as well as gas. This type of engine has a much lower specific rating than the aero-engine derivative and is therefore much larger and heavier.

The industrial engine is supplied as a simple cycle machine, similar to the aero-derivative engine, or with a regenerator (exhaust gas to air heater) to improve the specific fuel consumption. The engine is often installed with a waste heat recovery steam boiler which supplements the useful output by means of a steam turbine operating from steam from the boiler. This system has the acronym COGAS, and has a very favourable specific fuel consumption even when operating at part load.

The combustion temperatures of these machines are lower than the aero-derivative machine and the hot sections of the machine are coated to minimise corrosion. Nevertheless the MTBO will increase significantly if clean fuel and combustion air are used.

Industrial engines are designed and manufactured by a number of companies, the principal being; General Electric Co., USA; Westinghouse Electric Co., USA; KWU, West Germany; Brown Boveri Co., Switzerland; and Sulzer Bros., Switzerland. Industrial gas turbines which are presently available are rated from about 5 MW to over 100 MW. These engines do not require significant modification to make them suitable for shipboard use.

5.4.6.3 Steam Turbines

There are very few icebreakers fitted with steam turbine systems. The Canadian icebreaker CCGS Louis S. St-Laurent is fitted with a 20 year old steam turbine electric system and oil fired boilers, and the USSR nuclear fueled icebreakers are fitted with more modern steam turbine systems.

The most recent steam turbine vessel to be built is a LASH type barge carrier for the USSR for Arctic service. This ship is powered by cross compound turbines rated at 30 MW arranged to drive a controllable pitch propeller through double reduction gears. The steam turbine is to be powered from steam generated by a nuclear fueled boiler.

Steam turbines can be constructed for virtually any power requirement. Machines for electrical power generation in land plants exceed 1000 MW. The largest units built for ship propulsion are rated at about 50 MW but this limit is related to the power which can be absorbed by the propeller and not a limit imposed by the engine. Marine steam turbines with output power in excess of 100 MW have been proposed (MacDonald, 1977). Turbines are suitable for driving electrical generators at constant speed, or for directly coupling to the propeller via gears as a variable speed propulsion engine.

There are two types of steam systems used for marine propulsion. The most common system is the simple steam cycle employing one or more single superheat boilers, three stages of feed heating and a regenerative condenser. Boiler conditions are between 40 - 60 Bar, superheated steam temperature between 450 - 480° C. The second, and less popular, steam cycle is the reheat cycle which is similar to the simple cycle except that steam is returned to the boiler from the turbine at about 15 Bar and the steam temperature is raised to about 450° C. This system increases the efficiency of the cycle by 5-7% (Smith, 1983).

The general efficiency of marine steam turbines is about 20% compared to close to 50% for modern marine diesel engines. In an attempt to increase the efficiency of steam turbine machinery and to compete with diesel engines, steam turbine system designers have proposed to increase steam conditions to over 100 Bar and above 600°C superheat temperature. None of these very advanced systems was ever constructed for ship propulsion.

Steam turbine engines are uni-directional and, to provide astern power, must either be fitted to an electric transmission system or, if fitted to a direct drive system, a reversing turbine, a reversing coupling or a controllable pitch propeller. In open water ships it is common to fit steam turbines as direct drive engines and provide a simple low efficiency and low power astern turbine. For ice class vessels which require at least 70% of ahead power as astern power, by 'rule' requirements, the turbines have been fitted to electric transmission systems, which has the benefit of allowing full astern power to be developed with the same turbine efficiency as far ahead power.

Turbines have a rising torque characteristic under stall conditions and at full stall about 2.5 times normal full load torque can be developed. Full stall cannot be permitted, however, without incurring severe damage to the turbine and gears if fitted. Damage will be due to turbine casing hogging by differential expansion which would lead to a bent rotor. Damage to turbine blading may also take place. Damage to the gears will be due to scuffing because of poor lubrication of the gear teeth at high torque and at low or zero speed.

Turbine systems are flexible and can operate at any power within the rated range. However, fuel efficiency is poor at reduced power. Although the boilers of the steam system can be designed to burn virtually any liquid fuel, the greatest disadvantage of steam turbines is their very poor fuel efficiency when compared to alternative engines. Not only is the comparitive fuel efficiency poor at full load, the efficiency deteriorates sharply as turbine load decreases. Efficiency can be improved at part load but only at the expense of manoeuvrability (Fagerjord, 1982).

The manoeuvrability of steam systems is good if the system was originally designed for quick manoeuvres. Quick manoeuvres require generous internal clearances in the turbine which often result in reduced overall efficiency. Generally, turbines can manoeuvre as quickly as the boiler will permit. The older type of boilers with comparitively large water volume manoeuvred slowly due to the heat retained in the boiler which required time to disipate as load was reduced. More modern boilers have less brickwork and less water volume and manoeuvre more quickly. However the rate of change of load is limited by the size of the steam drum as water level will rapidly change due to the relationship between steam and water volume in the boiler at different loads. A boiler which is designed for rapid manoeuvres will have an extra large diameter steam and water drum.

The use of steam turbines for ice class ships is confined to ships which are required to burn special fuel such as coal, nuclear fuel or natural gas. Steam turbines were once the only system which could burn natural gas, but slow speed diesel engines are now being introduced which can burn gas efficiently and turbines are likely to be displaced even from this application. It is possible that if the spread in price of the very worst quality bunkers increases to a sufficient extent such that diesel engines are unable to burn the heaviest and cheapest bunkers available, steam turbine systems may become competitive.

5.4.6.4 Medium Speed Diesel Engines

The most popular engine for the propulsion of icebreakers and ice class cargo ships is the medium speed diesel. This popularity is based primarily upon the engine's compactness, light weight, fuel efficiency and good reliability. Its disadvantage for use in ice class ships is its lack of significant overtorque capacity.

This type of engine has been fitted to many icebreakers using diesel electric propulsion although there are an increasing number of privately owned icebreakers fitted with medium speed engines driving a controllable pitch propeller through gears. The use of electric transmission permits high torques to be developed through the speed range of the propeller and clamps ice torques being transmitted to the engine. Some of the direct drive systems are fitted with fluid couplings between the engine and gearing allowing full load torque to be developed at reduced propeller speed. The coupling also prevents transient torques above 100% from being transmitted to the engine. Both the electric transmission system and the fluid coupling will prevent engine stall under the most severe propeller overload condition. The USSR cargo vessels SA15 are fitted with fluid couplings between the engines and the gearbox.

All of the Canadian private icebreakers are fitted with geared medium speed engines and controllable pitch propellers and none have engine overload protection other than propeller pitch shedding systems when more than 100% fuel is demanded by the engine governor.

With one exception, all icebreakers, both Government owned and private, burn distillate fuel in the engines. In ships which operate in the Beaufort Sea dewaxed diesel fuel is used, similar to kerosene. The use of distillate fuels with low pour point eliminates the requirement to heat the fuel. The only vessel which operates in the Arctic with a heavy fuel burning medium speed diesel engine is the Canadian cargo ship M.V. ARCTIC. This ship has operated in the Arctic during the period June to November for the past seven years and has burned IF180 fuel without difficulties.

The operation of diesel engines in the Arctic results in problems of heating the combustion air and regulation of the charge air pressure. This is because at very low air temperatures the density of the combustion air increases considerably (15% increase of density at minus 40° C from 0° C and 25% increase in density over the design ISO conditions). This increase of air density causes higher than rated charge air pressures which leads to higher than rated cylinder pressures. Unless this is corrected, bearing overload may occur and there will be a greater potential for engine wear and failure. Various manufacturers have proposed systems to address the over-pressure problem. One proposed system is to fit a pressure relief valve on the charge air manifold and to relieve the over pressure back to the inlet to the turbo-charger (Sulzer, MAN and Wartsila). The other system is to fit an air heater to the turbo-charger inlet (MAK) with heat for the combustion air supplied from the engine central cooling water system. Both systems have been fitted and are reported to operate without problems (Paro, 1983; Oehlers, 1984).

Medium speed engines have undergone considerable development over the past ten years to improve fuel economy, burn heavier grades of fuel, increase routine maintenance intervals and increase the power per cylinder. The result of this development is that the most recent engines of this class can burn fuel of IF 700, and the largest engines have a cylinder output of about 1.2 MW per cylinder. The largest medium speed engines can now develop about 22 MW at 400 RPM in the 18 cylinder Vee form.

The largest medium speed engines are designed by European designers; Pielstick, SWD, B&W-MAN, MAK and Sulzer Bros. and built under licence by many manufacturers throughout the world. There are many other companies such as Wartsila, MWD, Deutz, Mirlees, Mitsubishi, Yanmar, etc. who are also significant manufacturers of smaller engines.

The engines are mostly uni-directional and therefore require a separate provision for astern operation. Usually astern power is provided by a controllable pitch propeller when direct drive systems are used although there are open water ships fitted with reversing gear systems. Some engines are capable of being reversed in an emergency but the available speed range of the engines are limited to an idle speed of about 150 RPM, in the best case, and they are not therefore suitable for direct reversing applications.

The specific fuel consumption of the engines is low and low grade fuel can be burnt in most of the more modern engines and blended fuel in many of the older engines. Typical specific fuel consumption of the engines is between 200 and 170 g/kW.HR. The lubrication oil consumption is a considerable operational cost for trunk piston engines. The consumption of lubrication oil is generally between 1.5 and 3 g/kW.HR in practice although the manufacturers of the most recent engines quote consumptions of 1 g/kW.HR.

The torque characteristic of supercharged diesel engines depends upon the characteristic of the turbo-charger. In recent years the development of the diesel engine is closely linked to the development of more efficient turbo-chargers and turbo-charging systems. Most medium speed engines are presently turbo-charged with the pulse system. The most modern medium speed engine is fitted with a constant pressure system. The constant pressure system provides the best fuel efficiency at the high power end of the engine range whereas the pulse system provides better turbo-charging at the low end of the power range. Therefore, the pulse charged engine provides greater flexibility and is more suitable for use in vessels such as icebreakers. However as the need of open water ships drives diesel engine development, it is probable that most future large medium speed engines will be designed with the constant pressure into changing system.

The torque characteristic for a typical diesel engine is shown on Figure 5.4.10. Diesel engines are essentially constant torque machines and at any given load torque may increase above rated by about 10%. If more fuel is supplied smoke is emmited (poor combustion) and the engine will tend to choke and the turbo-charger surge. The maximum torque is governed by the BMEP in the cylinder which is related to fuel and air flow. In general, the maximum torque can be developed in the speed range of 50-100% for pulse charged engines. If constant pressure turbo charging is used, the maximum torque can only be developed at full power and RPM.

Diesel engine flexibility is generally acceptable. Engines can operate to between 25 and 35% of their rated speed depending upon inertia of the rotating parts, fuel injection equipment and the turbo-charger characteristic. Many engines which can operate with heavy fuel must burn distillate fuel to prevent engine fouling when operating at low load for extended periods. The engines can be manoeuvred rapidly, limited only by the characteristic of the turbo charger, although modern turbo-chargers are of light weight and can accelerate quickly.

At present, medium speed diesel engines are manufactured up to 22 MW in a single engine, therefore over 80 MW (107,000 HP) can be provided for a four engine two shaft system, rating the engines at 90% of the MCR rating. The principal disadvantage of this system is the large number of cylinders (72) which must be maintained. However, full power is rarely required, and normal operation would be on only two engines. The greatest disadvantage of diesel engines for Arctic ship propulsion, when direct drive is used, is the lack of over-torque capability. This deficiency can be rectified by the use of fluid couplings, but about 3-5% loss of efficiency will be incurred. Experience of ships which are not fitted with fluid couplings tends to indicate that the requirement for engine over torque protection may be exagerated.

It is expected that medium speed engines will continue to be the preferred engine for Arctic ship propulsion for all vessels required in the immediate future.

5.4.6.5 Slow Speed Diesel Engines

The USSR LASH ship Alexsei Kosygin is the only Arctic class icebreaking ship in which this type of engine is fitted. In this ship, two 7 cylinder B&W engines are fitted, each of about 13.4 MW driving a fixed pitch propeller. There have been no reports of how the vessel performs in ice.

There are other USSR ships fitted with slow speed diesel engines which operate in ice, although most of these ships operate in convoy with icebreakers.

The slow speed diesel engine is the only prime mover which has been specifically developed for ship propulsion. All present day engines of this type operate on the two-stroke cycle, are cross head engines and are reversible. The engines are designed to be directly coupled to a fixed pitch propeller although some engines have been fitted with controllable pitch propellers.

The speed range occupied by the slow speed diesel engines is from 60 RPM to about 225 RPM and the largest engines are rated at the slowest speed. Engine size ranges from about 250 mm cylinder bore to 900 mm bore, the largest engines are rated at about 3.7 MW per cylinder and are available as in-line engines with up to a maximum of 12 cylinders.

Slow speed diesel engines are very large and heavy, and consequently they are only fitted to vessels which can provide a sufficiently large engineroom and can carry the additional weight without an unacceptable penalty. The engines are most often fitted to bulk cargo ships, oil tankers and container ships. Ships with limited head room such as ferries, Ro-Ro ships and barge carriers generally use medium speed diesel engines.

The development of the slow speed engine over the last ten years is remarkable. The two major developments have been the very large improvements made in turbo-charger technology and the adoption of ultra long stroke engines. The increase in the efficiency of the turbo-charger has allowed constant pressure turbo-charging to be used and higher mean effective pressures. The adoption of long strokes and uniflow scavenge permitted higher ratings per cylinder and lower propeller speed to be achieved. The slower turning propeller without the use of gears allowed higher efficiency propellers to be used in the large bulk carriers and oil tankers.

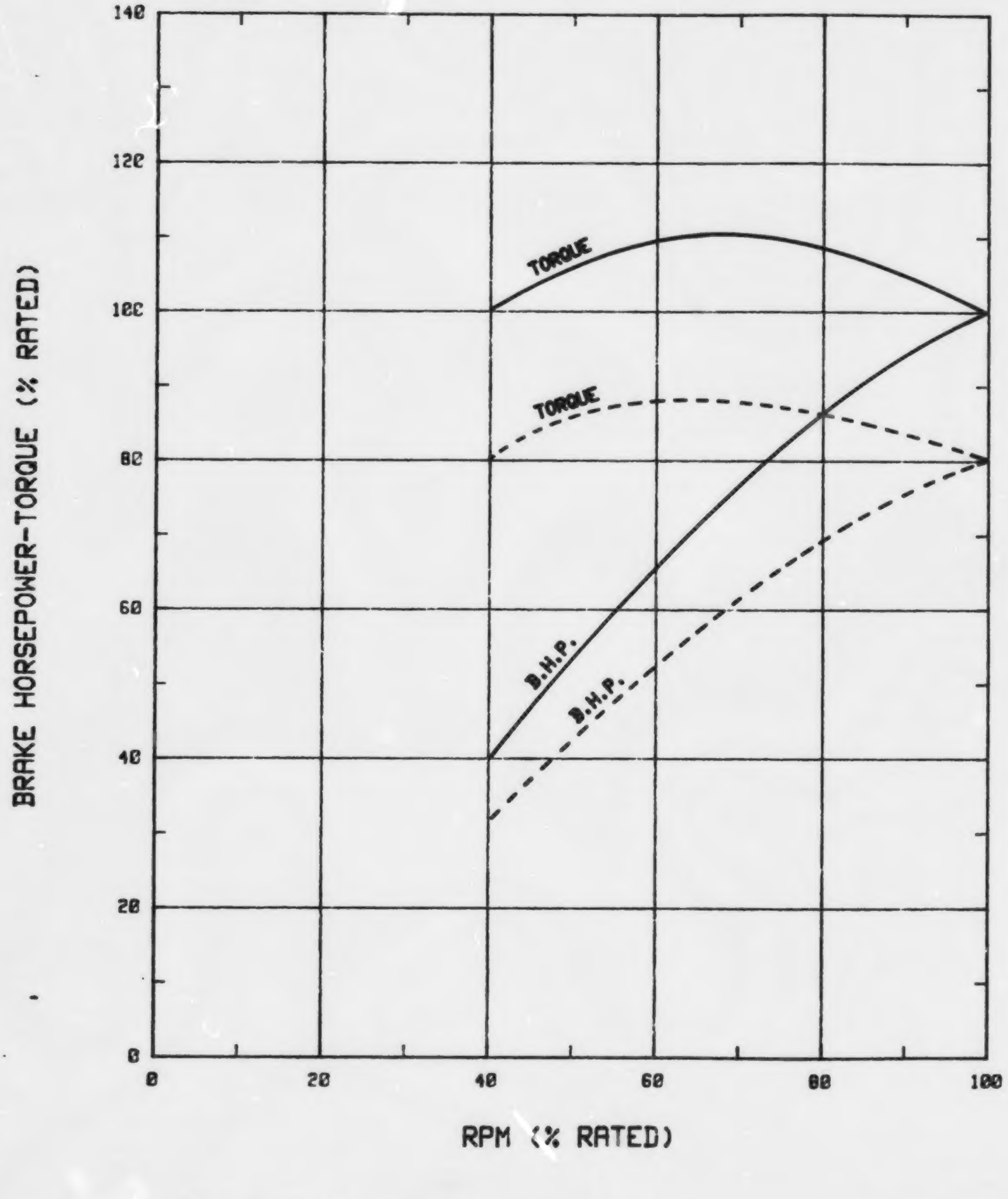
The specific fuel consumption of these engines is below under 160 g/kW.hr for the large economical engines and below 175 g/kW.hr for the smallest engines. If waste heat is recovered from the exhaust gases either by the use of a gas turbine or waste heat boiler and a steam turbine, the overall fuel consumption can be reduced further. Of great importance is the engine's ability to operate economically and reliably when burning very low grade fuel.

The manoeuvrability and flexibility of the slow speed engine is not so good. The manoeuvrability, while adequate for most purposes, is influenced by the relatively large rotating masses and the inability to develop over-torques at low speed to accelerate the engine and propeller. The use of constant pressure turbo-charging, while providing very low specific fuel consumption, does not provide large volumes of excess air at low engine loads. Although the turbo-charger is adequate to provide sufficient air at low load, an auxiliary electric blower is often required for start-up.

Although the engines are mostly used with fixed pitch propellers, ships with slow speed engines and controllable pitch propellers are in service. This combination is used when rapid manoeuvring is required, but stopping and reversing the engine is judged to be inappropriate.

FIGURE 5.4.10

TORQUE CHARACTERISTIC FOR A TYPICAL DIESEL ENGINE



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While slow speed engines cannot be judged to be unsuitable for use in Arctic ships, it is probable that for most purposes medium speed engines would be a better choice. This is because medium speed engines are less expensive and can provide better flexibility through the total probable power range of a large ice class ship. Slow speed engines can only be used in direct drive propulsion systems.

5.4.6.6 Combined Drives

The use of combined drives is for two reasons, both economic:

- To improve fuel economy by recovering waste heat and converting the heat into mechanical work.
- To offset the poor part load fuel characteristic of the high power primemover by the provision of a more efficient engine for low load operation.

Waste heat recovery systems often use waste heat in a boiler to generate steam which is then expanded through a steam turbine to either supplement the power of the primemover or to separately drive an electrical generator. When this sytem is used in conjunction with a gas turbine the system is termed COGAS. In merchant ship practice a similar system is in common use with diesel engines.

The only Arctic class vessels fitted with combined systems are the USCG icebreakers POLAR STAR and POLAR SEA. These ships have three Pratt and Witney FT4 aero-derivative gas turbines each driving a controllable pitch propeller through reduction gears, plus a diesel electric propulsion system. This is an either-or type of system. The gas turbines are intended for use when full power is required, such as heavy icebreaking, and the diesel electric system for use when cruising or for light icebreaking. The systems do not operate together. This is a good example of making use of two different systems for widely different power requirements in the overall interests of economy. There are other similar systems in use in the Baltic Sea Ferry FINNJET and other ships.

One system which may have an application for ice class ships is that favoured for the large LNG ships of the Arctic Pilot Project. These vessels were required to burn natural gas and were to be fitted with 112 MW. From evaluation of the alternatives, aero-derived gas turbines were selected and waste heat recovery boilers and steam turbines were to be used to improve fuel efficiency, especially at part load. It was not fully determined if this system could operate safely under variable load conditions but the indications were that it could and would produce significant benefits (Thompson, 1983).

Future large Arctic class ships with very large power requirement for the most severe icebreaking conditions are ideal candidates for combined drives. Mission profiles of Arctic ships indicate that maximum power is required for only a limited period of time and the propulsion system must be sufficiently flexible to enable that power to be developed at maximum possible efficiency. As the power requirement rises this requirement for efficiency becomes greater due to the potential savings to be made in fuel.

The expense of a combined system is only likely to be justified if the quantity of fuel to be consumed by the ship is substantial and the capital cost of the system can be justified.

5.4.7 Information Deficiencies

The deficiencies in relation to propulsion are in the areas of the design loads which may be expected, the methodologies for designing system components to these loads, and the limitations of present manufacturing technology. It is these areas which govern the size and therefore economics of propulsion machinery, and as a result will have most influence on the viability of future Arctic shipping systems.

a) At present, CASPPR and the rules of the classification societies use the Finnish-Swedish ice class rules as the model to calculate the shafting diameter for Arctic class ships. This formula is empirical in nature and developed to suit the needs of relatively small and less powerful ships.

   The various rules used to calculate shaft size should be examined for various sizes and classes of ships, and for various propeller weights. Using the calculated shaft size and the assumed propeller weight, the shafting principal stresses should be determined using agreed ice overload factors to ensure that sufficient margins or safety factors are provided by the formulas.

b) Medium speed diesel engines are technically the least favourable engine for Arctic service due to poor over-torque characteristics and the potential for overload when ingesting very cold air. There is also a certain amount of evidence to suggest that engine pistons and liners may experience a higher rate of wear when operating in the Arctic that in more temperate waters. Operating experience should be investigated to ascertain the extent of these problems.

c) There is considerable reluctance on the part of operators to burn heavy fuel in engines which operate in the Arctic. However, there is no theoretical reason why heavy fuel should not be burnt in these engines provided procedures are followed. At least one Canadian vessel habitually operates with heavy fuel in the Arctic. If operators can be convinced that heavy fuel operation can be successful and economical, a considerable saving can be made in the cost of bunkers and preservation of high grade fuel resources.

d) Icing of intakes to the engine room and engine has potentially serious consequences. It may cause engine damage, cause the engine to stall and endanger the ship, cause blow back from boilers and even cause a sufficient pressure loss in the engine room to result in damage to bulkheads.

e) An important parameter to be determined when designing a propulsion system for Arctic class ships is the loads on the propeller and shafting system brought about by ship/ice interaction. There is very little knowledge of the actual loads. The guidance provided by the CASPPR and classification societies rules are not based upon present day evidence and knowledge.

The design loads for the propellers of Arctic ships should be based on both full scale measurements from existing ships and modern theory. Ice loads related to ice class, ship length and draft and propeller type and protection should be proposed with the intent to provide the designer with more reliable guidance and to update the present regulatory approach.

f) The shafting loads can be increased due to the influence of ice entrained in the propeller. The additional load will be additive to normal shafting and sterntube bearing loads and may prove to be significant. At present there is no requirement by the rules to consider added mass due to ice (although in rational alignment calculation added mass due to water is allowed) and there is no requirement to consider the influence of propeller ice loads on shaft line bearing loads, the assumption being that a sterntube bearing length (for an oil lubricated white metal line bearing) of 1.5 D will provide a sufficiently large bearing area.

g) The problems of transmission, to the primeover, of axial displacements due to thrust bearing deflection must be studied to determine the true extent of this problem.

h) If ice ingestion by the propeller can be minimised, the design ice load requirement of the propulsion system can be reduced. At present there are no regulatory allowances to reduce the size of the propeller components to take into account the possible benefits of devices which may protect the propeller from ice loads.

i) Propeller shafting external seals are essential for oil lubricated bearings, and the continued efficiency of the shaft sealing system are wholly dependent upon shafting rubbing speed, shaft surface finish, shafting roundness, shafting stability and lack of axial movement of the shafting in the seal. The efficiency of this type of seal quickly diminishes as shafting diameter increases. The limitations in the use of shaft seals, both lip and face type, should be investigated.

j) In the present rules there are regulations specifying the machinery system in terms of ice torques but no regulations which specify the ice thrusts to be used. The probable over-thrusts for ice class ships should be assessed with a view to inclusion in the Regulations.

k) For large ships with high power, the size of shaftline components will increase beyond present manufacturing experience. There are dangers in increasing sizes regardless of the influence of size on quality and reliability. The present limitations in the manufacture of shaftline components, seals, bearings, shaft length and diameters, couplings, etc. should be determined along with the means of ensuring that quality standards can be reliably met when size is increased above present experience.

l) Regulations describe gearing transmission systems only in terms of over-torques, although factors such as alignment during ice load excursions, shock loads, over-torques under maximum stall conditions and other parameters are fundamental to the efficient operation of a gearing system.

m) Although the present CASPPR requires that the gearing of Arctic ships is to be specially protected from over-torques, this regulation is not applied as there are no known methods to carry out the intent of the regulations. However, the intent to protect the gearing from overtorques should be pursued and practical methods by which this can be achieved should be identified.

n) As gearing size increases, both physically and with respect to torque, the gear manufacturer has various choices to make. Either gear diameters must increase, gear tooth length increase, the K factor increase or a combination of all three parameters. Increases in these parameters should not be considered without a full understanding of the penalty, if any, and the compromises which may be required.

o) The parameters essential to the specification of a reliable gear design should be documented in order that the limits, if any, which presently exist to increasing gear size above present practice, can be understood.

5.5 General Outfit and Auxiliary Systems

5.5.1 General

The Arctic environment has an influence on virtually all items of equipment or systems onboard a ship. The equipment or systems which are most influence are:

- Deck machinery and equipment
- Mooring systems
- Steering systems
- Sea suction arrangements
- Ballast tank heating
- Lifesaving equipment
- Firefighting systems
- Icing protection
- Coatings
- Accommodation

The designer and operator must deal with problems in each of these areas, and the final design must couple the need for an efficient system with the constraints imposed by commercial considerations. This section reviews the design and operational experience with the general outfit and auxiliary systems identified above.

5.5.2 Deck Machinery

The major items of deck machinery and associated equipment which may be effected by the Arctic environment are:

- anchor windlasses
- mooring winches
- cranes
- hatch covers

Since this equipment is located in exposed positions it is therefore subjected to the extremes of temperature which can occur in the Arctic. These extremes have an effect on the reliable operation of the equipment and on the ability of the crew to perform the various operations. The three major concerns are the type and use of equipment, protection of the equipment from icing, and the protection of personnel during operation of the equipment.

a) Type of equipment

The deck machinery fitted on Arctic ships are of the following types: low pressure electro-hydraulic, high pressure electro-hydraulic, electric, and independent diesel driven.

The electro-hydraulic systems appear to be favoured over all-electric. The low pressure systems are most often of the central pumping/ring main type using large diameter pipes and robust fittings and equipment. The high pressure systems are usually self contained units complete with hydraulic oil tank, pump(s), motors, and piping. Independent diesel driven winches are fitted on few vessels, other than those which operate in the Beaufort Sea.

Experience with the M.V. ARCTIC (Stockdale, 1981) has demonstrated the need to run the deck machinery hydraulic systems for some time before use. While suitable low temperature hydraulic oil will alleviate this problem, precirculation of the hydraulic system will still be required. Low temperature lubricants are required to ensure that consistent performance qualities are retained in the full range of operating temperatures (Peravaimo, 1985).

Hatch cover seals are generally made of neoprene rubber and are satisfactory at normal temperatures. At very low temperatures neoprene becomes brittle and cracks, giving rise to rapid deterioration of the seal and the need for eventual replacement. Special low temperature rubber seals are available and should be used, particularly for sealing access to oil fuel or oil cargo tanks where ineffective seals will effect ship and personnel safety.

Recently constructed ships, such as the S.A. 15 class, have made extensive use of grade E steel in deck equipment. Use of this steel is generally confined to components which may be exposed to shock loading, such as the running components of cranes (Motorship, April 1983; Peravaimo, 1985).

b) Problems caused by icing

All deck equipment, but particularly those items forward of midships, is susceptible to the effects of icing. On the M.V. ARCTIC (Stockdale, 1981) and presumably on most Arctic or cold environment ships, the forward deck equipment must be de-iced before use. Ice is generally cleared away using ice mallets or hot water and steam may be available. Hot water and steam do have an immediate effect although they tend to create more ice around the deck leaving a subsidiary problem to be dealt with.

The sheltering of deck equipment is a solution to the icing problem. The shelters must be designed to allow easy access by crew and to facilitate communication between members of a crew team (such as during mooring operations).

c) Protection of operations personnel

Protection of personnel during deck operations is very difficult due to the need for mobility, and the large space required for some activities, such as mooring. This has been addressed by several designers for ships which may operate year round in the high Arctic. Mooring arrangements have been enclosed in forecastle and poop spaces with heat provided to create a more normal working environment.

The only major feature which has been consistently adopted for personnel protection is the insulation and heating of crane cabs (Stockdale, 1981, Shipbuilding and Marine Engineering International, December 1982). Access to the deck cranes has been arranged on the SA 15's via an enclosed passageway. The operating personnel need not go outside at any time.

The deck machinery presently being used on Arctic ships has generally performed adequately. Experience has been gained with all of the major system types and, while there are specific benefits associated with each option, all appear to be technically acceptable. Special care must be taken with the choice of materials, hydraulic oil and lubricants, and with the protection of equipment against mechanical damage. Protection from ice accretion and means of de-icing must be considered, and the protection of personnel during outdoor operations will be important for year round operations in the Arctic.

5.5.3 Mooring Systems

Mooring systems for Arctic ships must accomplish the same functions as those on non-Arctic ships. However, the unique environment places demands not present for other ships on both the equipment and operators.

There are several criteria for the selection of mooring lines for operation in the Arctic. The mooring lines must:

- have high energy absorbing properties
- be unaffected by strong sunlight
- be of light weight and easy to handle
- be capable of operating in a temperature range of 30°C to -40°C

The materials normally considered for mooring lines are:

- wire rope
- natural fibre, such as Manila
- synthetic fibres, such as
    - nylon
    - polypropylene
    - polyester (terylene)
    - polyethylene

The energy absorbent properties of wire rope, manila and synthetic fibres are shown in Figure 5.5.1. The area under these curves indicates the energy absorbing qualities of each material. It can be seen that wire rope has very little energy absorbing capability. For this reason and since wire rope can be cumbersome to use, it is not the preferred material for Arctic mooring lines (Lumsden, 1980).

Information on the low temperature properties of fibre ropes was assembled by Lumsden from a number of sources. This work concluded that:

- in their normal dry state, low temperatures do not effect any of the synthetic fibre ropes beyond some embrittlement of polypropylene.

- when the lines are wet before cooling, the natural fibre ropes lose a considerable part of their tensile strength, whereas the synthetic fibre ropes are generally unaffected.

- synthetic fibre ropes remain more flexible than natural fibre ropes and, due to their lower water absorbent properties, they handle well at low temperatures.

The most suitable synthetic fibre rope material appears to be 'polyester' (terylene). It stands up well to the effects of strong sunlight and is unaffected by very low temperatures. Although heavier than other fibres it can still be handled quite easily, particularly when drum mounted on a tension winch. Eight strand multiplait ropes remain the most pliable at very low temperatures.

The forces acting on a ship's mooring system have been measured at model scale for a ship berthed at a future Arctic port (Acres, 1981). The results indicated the desirability of installing a mooring line force measuring system as part of the ship's normal operating equipment.

The arrangement of mooring equipment on Arctic ships is similar to that on non-Arctic ships. However, the handling of mooring lines in very cold weather is an unpleasant task and could be made easier by enclosing the mooring areas. Seafarers would seem to endorse some form of shelter (Stockdale, 1981) but with special attention being paid to access to equipment and line of sight for communication between mooring crew members.

The mooring systems presently used on Arctic ships are similar to those on non-Arctic ships, and appear to have performed satisfactorily. However, consideration is now being given to enclosed mooring flats, strain gauging the mooring lines to measure forces acting on the ship, and using polyester as a material for the mooring lines.

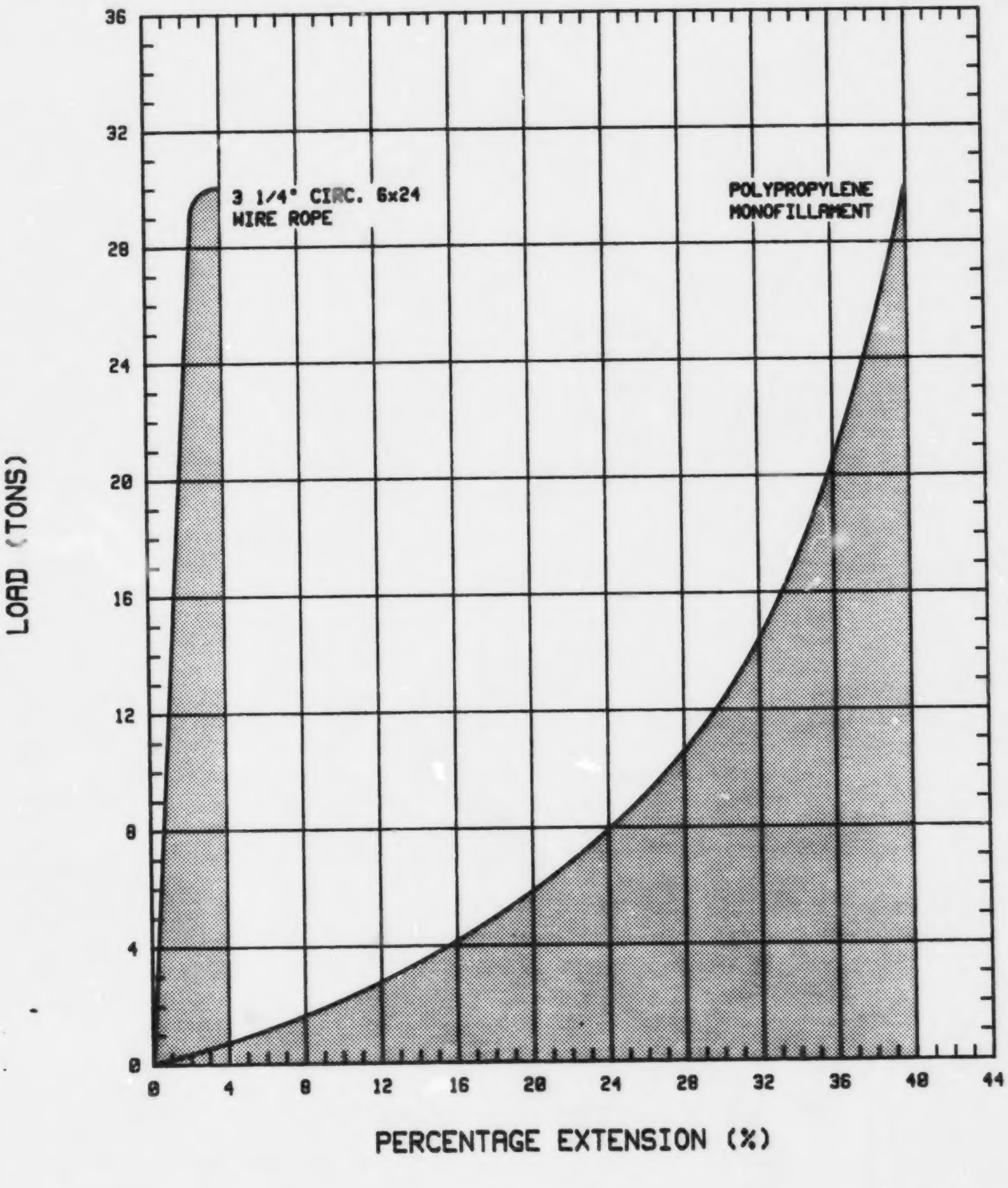
5.5.4 Steering Systems

Steering systems usually consist of a steering gear connected to a tiller, which in turn is attached to a rudder stock and to the rudder. The system may use one or two rudders, depending on the number of propellers. It would be usual to place one rudder behind each propeller of a twin screw ship but only one rudder on a triple screw ship.

Typically the steering gear is of the electro-hydraulic type, utilising electrically driven variable delivery pumps to deliver oil to rams working in hydraulic cylinders. The rams are arranged to operate the tiller which is keyed to the rudder stock. Depending on the design, the

FIGURE 5.5.1

ENERGY ABSORBING PROPERTIES OF WIRE AND SYNTHETIC FIBRE ROPES



systems may be of the two or four ram type with single or double acting rams. The following ships are fitted with a two ram double acting system:

- CCGS Pierre Radisson (R Class)
- M.V. Canmar Kigoriak
- M.V. Robert Lemeur
- M.V. Terry Fox/Kalvik
- M.V. Ikaluk/Miscaroo
- M.V. Arctic

The power required for these systems depends on the size of the rudder and the maximum speed of the ship. These parameters are translated into rudder stock torque, which in turn is related to hydraulic ram size and pressure, which determines the steering gear power.

The present practice on Arctic ships is to support the rudder at top and bottom with pintles and bearings. In the case of many icebreakers, several pintles are used to attach the rudder to a rudder post, which in turn is attached at the top and bottom to the ship's sternframe. The more standard arrangement used on open water ship's is to have an upper bearing and a lower pintle ie, only two supports. This arrangement is now being used on icebreakers and other ice capable vessels.

Protection of the rudder, particularly when a ship is moving astern, is usually provided in the form of an ice horn or by an ice deflecting stern shape.

Experience with electro-hydraulic steering gears on icebreaking ships has been good. Although some statistics have been assembled (Menon, 1979) on steering system damage, very little data exists on which to determine if the steering systems on Arctic ships are more at risk than those on non-Arctic ships.

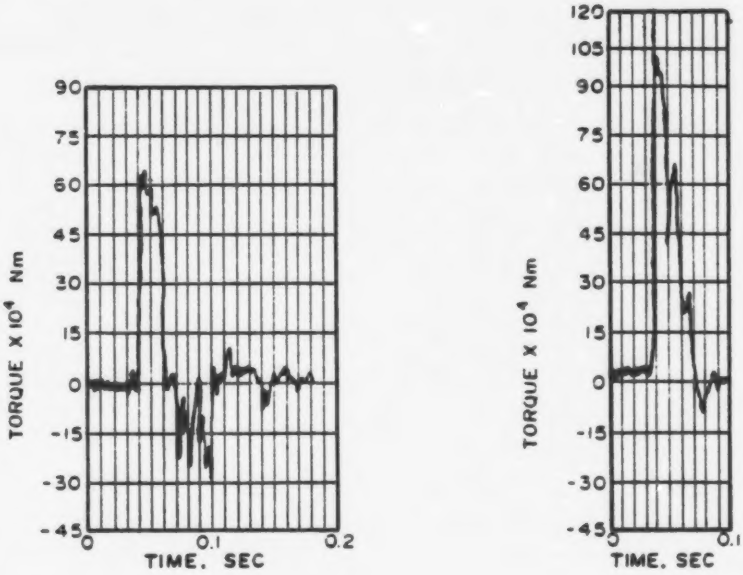
The Menon data indicate that rudder stock failure accounts for about 50% of the cases reviewed, and the failure of rudders, tillers or steering gear account in approximately equal quantities for the other 50%. The reported damages can be caused by a number of mechanical or material defects, or by overloading of the system caused by ice interaction between ice and the rudder. It is this latter reason which is used by regulatory authorities, and which has been the subject of recent research.

Measurements of rudder stock torque due to rudder/ice interaction were taken on the POLAR STAR, NAUGATUK, PIERRE RADISSON, and LOUIS S. ST-LAURENT (Arctec, 1984). This data indicates that the ratio between the torque due to ice interaction with the rudder and that due to turning in open water can be as high as 5.0. In addition, the frequency of high torque ratios appears to be greater during astern operation.

The duration of the rudder stock/ice interaction can be important when considering the reaction time of the steering gear hydraulic system. An example time history of rudder stock torque due to ice interaction is shown in Figure 5.5.2 (Menon, 1979). It can be seen that the duration of each event can be less than 0.1 second.

FIGURE 5.5.2

EXAMPLES OF FULL SCALE TORQUE-TIME HISTORIES IN RUDDER STOCK



Most of the regulatory authorities and classification societies have adopted a similar approach to the minimum requirements placed on the steering systems of Arctic ships. The present design recommendations for steering gears subjected to operations in ice can be summarised as:

- the steering gear must move the rudder from 35° on one side to 30° on the other side in 2.56 L seconds. This requirement relates only to the steering gear power.
- a shock absorbing device must be fitted, usually in the form of a relief valve in the hydraulic system. These valves are intended to limit the effect on the steering gear system of ice loads.
- rudder stops should be installed external to the steering gear to prevent steering gear damage due to impacts.
- an auxiliary steering gear must be installed. However, if the main gear comprises two or more identical units then the auxiliary gear is not required.
- the steering gear torque can be determined by the largest of: the rudder torque calculated for the full ahead speed with the rudder hard over, or the torque calculated at half speed astern. Several classification societies and the USSR have requirements for Arctic ships which exceed these normal open water criteria.
- an ice horn must be provided to protect the rudder from ice for 2° on either side of the centreline.

However, none of the regulatory requirements consider the duration of rudder/ice interaction. It has been believed that fast acting relief valves could react quickly to eliminate the effect of high torques, thereby negating the need to use those high values as system design criteria. However, the duration of the rudder/ice interaction can be less than 0.1 second, possibly too fast for relief valves to have any effect. Notwithstanding this, the low incidence of damage to steering gears indicates the success of the present design requirements.

It must be recognised that Canada presently has no year round operating capability in the Arctic and that future ships may be faced with more onerous operating conditions. Present practice may prove to be inadequate for high Arctic class ships which must manoeuvre in multi year ice. Only a greater understanding of the rudder/ice loads, and of how these loads are absorbed by the steering gear system, will give confidence that the present design requirements are still acceptable.

5.5.5 Sea Suction Arrangements

The clogging of sea suctions is a common operational problem on Arctic ships, particularly ships with a light draft. The ice either blocks the inlet grill or, more commonly, enters the sea bay and blocks the suction pipe directly. Either event will result in a rapid increase in temperature of the cooling system water and a main engine shutdown or reduction in power level.

There are several design features which can ease or eliminate these sea suction problems:

- **High and low grills** should be provided. The grills should be as far apart as possible, with one high grill on the ship's side and one low grill on the bottom.

- **Weir-type sea inlet boxes** will overcome the problem of clogging the suction pipe. The principle is commonly used in the Baltic icebreakers and is shown in Figure 5.5.3. The cooling system suction is separated from the sea inlet grills by a vertical plate weir. Any ice entering the box must float to the top of the box and is unlikely to be drawn back down to the level of the cooling system suction.

- **De-icing return(s)** can be arranged to feed steam or hot water to the top of the sea inlet box, where frazzle ice may have accumulated, or directly to the cooling system suction where a blockage may have occured.

- **Ballast recirculation** through the cooling water system allows the ballast tanks to be used as coolers, alleviating any need to use the sea inlet boxes.

These solutions should all be designed into the system to ensure no interference with the main engine operation.

The efficient operation of the sea inlet boxes is of great importance to Arctic ships. The main engine cooling system is normally fed directly from these boxes and any blockage will allow the cooling water temperature to rise above the permissable level. Solutions have been developed to maximise the efficiency of the sea inlet boxes, although these solutions are not always implemented on modern ships.

5.5.6 Ballast Tank Heating

The Arctic environment must be considered when designing fluid tanks which are exposed to the outside air. A recent investigation (Gauthier, 1983) reviewed the implications of the cold environment on the fluid systems of Arctic ships and concluded:

- The severity of ice buildup in ballast tanks is dependent on:

- ambient air temperature
- the time spent in the cold air temperature
- the length of the ballast voyage
- ship's freeboard
- design and geometry of the tank structure
- wind chill factor
- initial ballast water temperature
- ballast water salinity

- In ballast tanks, ice forms initially on the water surface and later on the tank structure exposed to the ambient air above the waterline. For this reason ballast tanks should preferably be located below the waterline, ie. with little or no structure exposed to the cold air.

- Where ballast tanks must be located above the waterline adjacent to the shell they should, preferably, be separated from the lower tanks to reduce the volume of water which must be heated.

The practical solutions which have been considered for heating the ballast water are; steam heating coils with the condensate return piping run through a dry duct keel, thermal fluid coils, recirculation of main propulsion cooling water through the ballast tanks, and continuous recirculation of all ballast water through the ship.

There is no doubt that care should be taken to locate ballast tanks away from the cold air, but the decision to install costly systems to heat the contents, piping systems or valves must be considered in the light of real experience. The problems may be resolved by more appropriate tank location or by the design of simple anti-icing or de-icing systems.

5.5.7 Lifesaving Equipment

The survival of personnel who abandon ship in Arctic waters will depend to a large extent on the type and quality of lifesaving equipment provided and the time before rescue. Of particular importance are:

- suitability of the equipment to prevent the survivors from drowning in a variety of conditions ranging from open water to closed pack ice.

- the type of clothing provided to insulate survivors from the extreme cold both when dry and when wet.

- the type of shelter and the ingenuity of survivors to improvise as required.

Except for open water, these conditions present to shipwrecked survivors a range of unique survival problems which presently are not recognised by the Canadian or any other regulatory requirements. At this time, the requirements of the Canada Shipping Act for Arctic ships are identical to those for non-Arctic ships.

Canada's formal Search and Rescue capability in the Arctic is untried and is unlikely to be fast in remote shipping areas such as northern Baffin Bay. In areas such as the Beaufort Sea the proximity of other ships or shore based aircraft may permit rescue within a short time. These considerations must play a part in assessing the adequacy or inadequacy of the present requirements for lifesaving or survival equipment.

Totally enclosed lifeboats and liferafts are recommended for use on Arctic ships in open water or open pack conditions where the risk of ice damage is low. In lifeboats or liferafts the crew will be sheltered from the wind and, with the necessary survival supplies and suitable clothing, they can wait for rescue.

Liferafts are also suitable for conditions where the ice cover is too great to allow lifeboats to be safely launched. The liferafts may be pulled over the ice away from the ship and used as on-ice shelters. Although liferafts may be used as enclosures to protect against the wind, inadequate inflation pressure between the two layers of floor material results in the survivors sitting directly on the ice. A new liferaft is presently being developed to increase the CO pressure between floor layers, incorporate automatically inflating seats, and provide a layer of thinsulate between the floors and within the protective canopy.

The major alternative to a suitable liferaft is the provision of Arctic tents of suitable capacity for all crew members (Melville, 1986). Suitable insulated tents are now being developed to sustain an acceptable survival temperature, fueled only by body heat.

Alternative lifesaving vehicles have been considered (Melville, 1984a), including:

- Sled boat
- Amphibious tracked vehicle
- Archimedian screw vehicle
- Lifesaving capsule

At this time only the Sled boat is thought to be practical for use onboard ships.

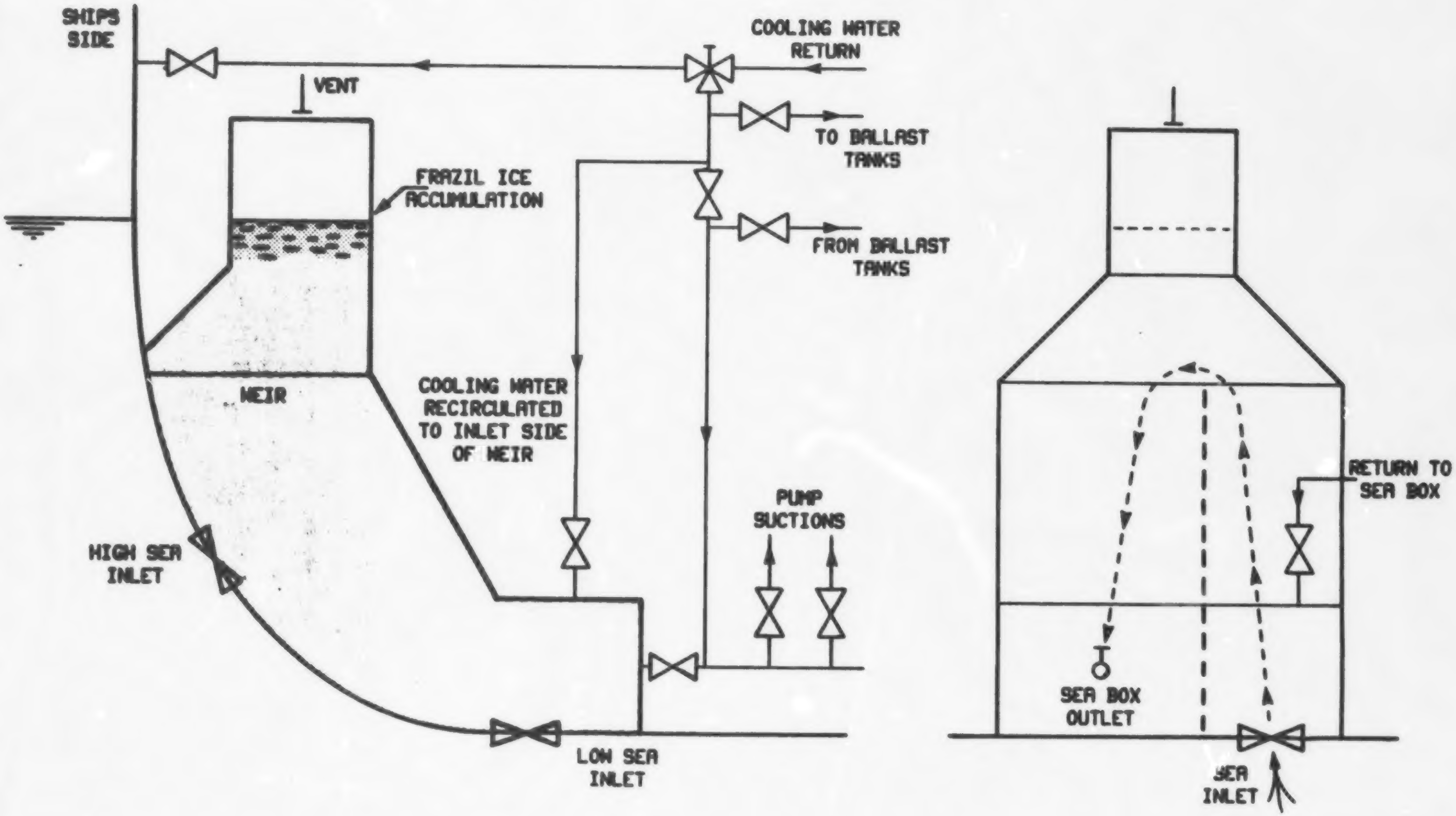
There are several types of clothing which have been thought to preserve body temperatures in the Arctic:

- **multi layer clothing** has up to six layers which provide insulation by trapping air between the layers and in the weave of the material. The number of layers can be varied to suit the conditions and to avoid perspiration.

- **single layer clothing** although more simple than a multi layer garment has two major disadvantages. If designed for the most severe temperature conditions the garment will be too heavy during warmer periods. And, secondly, the garment cannot be adjusted to account for different levels of physical activity.

FIGURE 5.5.3

ALTERNATIVE SEA INLET ARRANGEMENT


SHIPS SIDE
VENT
FRAZIL ICE ACCUMULATION
WEIR
HIGH SEA INLET
LOW SEA INLET
COOLING WATER RETURN
TO BALLAST TANKS
FROM BALLAST TANKS
COOLING WATER RECIRCULATED TO INLET SIDE OF WEIR
PUMP SUCTIONS
RETURN TO SEA BOX
SEA BOX OUTLET
SEA INLET

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- **wet suits** are unsuitable for use as survival clothing in the Arctic since they provide insufficient insulation either in or out of the water.

- **immersion suits** are designed to provide both bouyancy and insulation when in the water, but they are unsuitable as protective clothing out of the water. The suits are too bulky and are not designed to protect against extremely cold air temperatures.

Regulatory requirements for the training of crews in the deployment and use of lifesaving equipment in Arctic circumstances and for means of survival in the cold environment are virtually non existant.

The most recent research (Melville, 1985) has proposed two survival equipment schedules; schedule A applies to requirements for extreme conditions of ice and temperature, and schedule B to less hazardous conditions. The requirements of these schedules are shown in Table 5.5.1.

The application of these schedules to Arctic class vessels cannot be completely consistent but the schedules have been assigned to each Arctic class based on the time of year, the zone access permitted, the minimum air temperature and the ice concentration. Figure 5.5.4 is an alternative approach and shows the CASPPR zones, the ship class and the time of year which is applicable to each combination. Overlaid on this are the lifesaving equipment schedules from Table 5.5.1. There are several anomalies within this presentation, but it does indicate the direction in which todays thinking is proceeding.

The unique nature of the Arctic environment requires that special consideration be given to crew survival. The present regulations provide only for ship abandonment in open water with no special consideration given to the Arctic. Research has been performed recently which identifies the shortfalls of the equipment presently carried onboard ship. Further development and testing of survival equipment and supplies has been arranged and the results will be available in due course.

5.5.8 Firefighting Systems

The firefighting systems normally installed on Arctic ships have been based largely on the experience gained on non-Arctic ships. The special problems encountered relate to the cold air temperature and to the the icing of fire fighting equipment. To date these special circumstances have not resulted in major problems.

The firefighting systems normally fitted on ships must recognise the types of fires which may occur. There are four different types of fires:

- **Class A fires** are those which are caused by combustible materials such as wood, paper, cloth etc., and can best be extinguished by water, although foam or dry chemicals may be used.

TABLE 5.5.1

SURVIVAL EQUIPMENT SCHEDULES

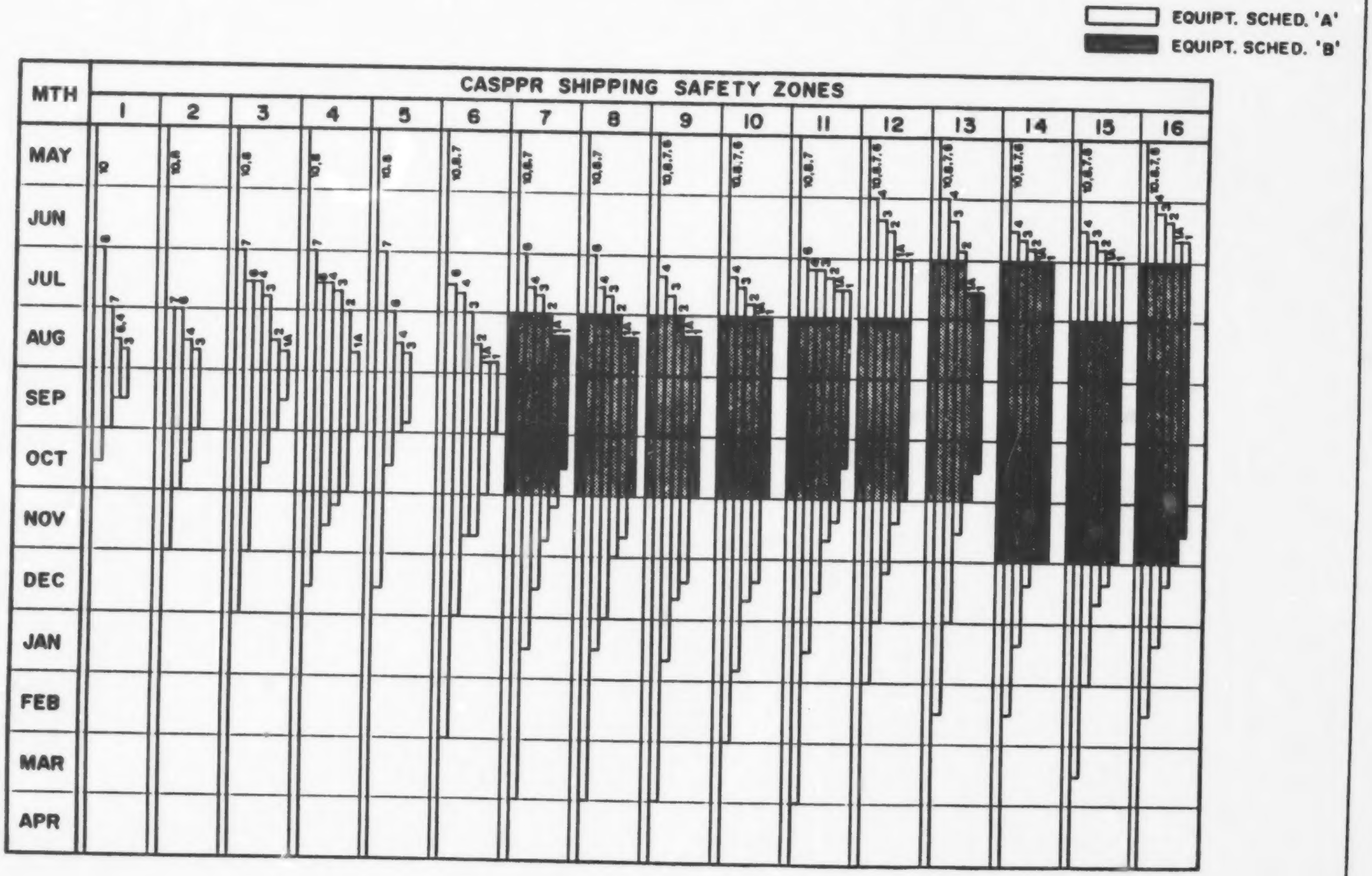
SCHEDULE A	SCHEDULE B
ARCTIC TENTS	ARCTIC SURVIVAL SUITS
SLEEPING BAGS	BALACLAVAS
INSULATED GROUND SHEETS	MITTS
ARCTIC SURVIVAL SUITS	"HEATPAKS"
BALACLAVAS	ARCTIC PROVISIONS
MITTS	ARCTIC FIRST AID KIT
"HEATPAKS"	
STOVES AND FUEL	
LANTERNS	
MATCHES	
ARCTIC PROVISIONS*	
COOKING/DRINKING UTENSILS	
SNOW SHOVEL	
SNOW KNIFE	
ARCTIC FIRST AID KIT	
POLAR BEAR DETERRENT	
SHOTGUN	

* Arctic Provisions Should Comprise:

  - A ration of 67,000 kJ per person, equivalent to 2,000 calories per day for 8 days.
  - Packets of coffee, bovril, cocoa, sugar and creamer
  - Hexamine tablets

FIGURE 5.5.4

VOYAGE BASED CREW SURVIVAL EQUIPMENT SCHEDULES



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- **Class B fires** are those which are caused by combustible liquids or gases such as crude oil, lubricating oil, or paints etc., and can best be extinguished by foam, dry chemicals, Halon, or CO gas.

- **Class C fires** are those which are caused by live electrical equipment and can best be extinguished by inert gases such as Halon or CO, but dry chemicals are also effective.

- **Class D fires** are those which are caused by combustible metals such as magnesium, titanium, or sodium and can best be extinguished by dry chemicals developed for specific metals.

The systems which are most commonly found on ships are:

- **Water systems** usually comprise a set of fire pumps, main and branch line piping, valves, hydrants and hoses. The pumps are normally in protected and warm spaces but the piping system is run throughout the ship, including exposed and cold areas.

  Protection of the fire main from freezing can be accomplished in a number of ways. Piping on the exposed deck must be self draining, supplied with drain cocks at the low points of pipe runs and kept drained except when required for use. While the hydrant valves and hydrants must be exposed to the atmosphere, the main and branch piping can be protected in warm void spaces or pipe tunnels. The hydrants can be insulated and heat traced to prevent freezing and may be protected from the effects of icing.

- **Carbon dioxide (CO2) systems** have been installed on ships for many years and, provided the air temperature in the CO bottle storage compartment is kept above about -18°C the efficiency of the system will be acceptable. If the storage temperature is lower, then the volume of gas must be increased by about 2% for each 1°C decrease (Melville, 1985).

- **Halon systems** have been installed in ships for many years. The systems which are presently used or approved are Halon 1301, Halon 1211 and Halon 2402. Halon 1301 is recommended for use at any temperature down to -57°C although its storage temperature should not be less than -29°C, and Halon 1211 is not recommended for use in ambient temperatures below -1°C. Halon 2402 ejects a stream of liquid which does not vaporise until it makes contact with the source of heat.

- **Dry chemical powder agents** include potassium bicarbonate, sodium bicarbonate and monoammonium phosphate. All of these chemicals are considered to be operational at temperatures down to -54°C.

- **Foam systems** mix foam concentrate, water and air to create air filled foam bubbles. The water and foam concentrate are led through a piping distribution system to nozzles where the air is induced and the foam bubbles are formed. All foams are subject to freezing at low temperatures, although the protein foam concentrates of a freeze protected composition enable satisfactory use down to -29°C.

Firefighting systems on Arctic ships must be carefully designed to ensure efficient operation in extremely cold air temperatures. Some systems such as dry chemical powders are uneffected by these extremes but the water, foam and, to some extent, the gaseous systems are adversely effected. The effectiveness of each of these systems has yet to be demonstrated during a major fire onboard an Arctic ship.

5.5.9 Icing protection

Ice accretion on the decks, superstructure and equipment of ships is normally caused predominantly by ocean spray (AES 1985, Stallabrass 1980). In the eastern Arctic the causes are divided between ocean spray (57%), fog (33%), and rain (10%). Statistics in the western Arctic are similar. As with ships in general, the effect of icing on Arctic ships is to decrease the ship's operational efficiency, particularly in relation to the use of deck equipment such as mooring systems and cargo hatch covers. There are also serious safety implications if lifesaving equipment, fire hydrants or radar antennae become inoperable due to ice accretion.

Research on icing has, focused on the stability problems faced by fishing boats (Stallabrass, 1980). However, some of the potential solutions reviewed in those studies may be appropriate for Arctic ships. There are two methods of decreasing the icing hazard: minimisation of ice buildup or de-icing, which is concerned with the removal of ice which has accreted on the ship.

Icing strategies fall into several categories (Stallabrass, 1980; Jorgensen, 1982; AES, 1985):

- avoidance of icing weather conditions by rerouting to avoid the combination of air, sea, and wind conditions which will create the most severe freezing spray situations.
- careful handling of the vessel to minimise the spray created when the bow slams heavy waves. A decrease of ship speed or a change of heading will often greatly reduce the spray.
- the design of exposed surfaces to inhibit the accretion of ice. This can be achieved in a number of ways:
    - . The ship's freeboard can be increased at the bow to reduce the chance of freezing spray reaching the deck equipment.
    - . The bulwarks can be designed to deflect spray.

- Equipment can be covered to prevent the accumulation of ice on moving parts or where access by personnel is important.

- A reduction in the number of stays, railings, wires and fittings will decrease the total volume of ice which accumulates on the ship.

- The use of heat tracing or other heating methods will increase the temperature of the surface being protected. This solution is most suitable for piping but is not suitable for large surface areas.

De-icing has in the past been accomplished by a combination of two methods (Makkonen, 1984): by chipping off the ice with axes, pneumatic hammers or hand hammers, or by the application of hot water or steam. The use of hammers and axes are very time consuming and can cause damage; hot water or steam require large volumes and will create more ice. Notwithstanding the drawbacks these are the predominent de-icing methods in use today.

The use of pneumatic panels, which can be wrapped around a piece of equipment or structure, has been tried successfully (Stallabrass, 1980; Jorgensen, 1982). Ice is allowed to accumulate on the panel before the panel is inflated. When the panel is inflated the ice is broken (in tension) and flakes off the surface. If the panel air pressure is then released the buildup and de-icing cycle can be repeated. This system can be effective for the protection of equipment or areas which cannot be enclosed, although preparation is required in terms of design and operational practices.

Other de-icing solutions have been proposed (Jorgensen, 1982; Makkonen, 1984) including thermosyphons, induced vibration, high pressure water jet cutting, infrared radiation, chemical sprays and special coatings. None of these options has been favourably received by ship operators as a practical alternative to the application of heat systems described above.

The most likely solution to icing problems is a combination of design features aimed at a) reducing the number of sensitive areas, b) protection of those areas and c) the supply of well designed hot water or steam systems to de-ice the equipment which cannot be otherwise protected. To supplement these precautions, inflatable covers will help to limit major ice accretion on the most sensitive engineering and electrical equipment.

5.5.10 Coatings

In past years the coatings which were used on icebreakers were ineffective to some degree. The extremely cold air temperature and the hull interaction with ice created operating conditions which were too severe for the coatings. After many years of research and experiments these problems are almost completely resolved.

The above waterline coatings must be resistant to extremely cold temperatures. Chlorinated rubber paint is now common on Arctic ships in applications above the deepest waterline. This paint is suitable for application and operation in cold temperatures. Other coatings may be used but are not considered to be as resilient.

The below waterline coatings must be resistant to the impacts and abrasion of ice. An associated requirement for those coatings below the waterline is the need for a low friction factor between the ship and ice.

Extensive research has been undertaken to develop a hull coating suitable for ships in ice (Calabrese, 1974). Below the waterline, two coatings are available; Inerta 160 (solventless epoxy) and Zebron (polyurethane). Inerta 160 is more widely used than Zebron and has been installed on about 300 ice class vessels in the last ten years. Both exhibit high resistance to impacts and abrasion and both offer a low 'coating/ice' friction factor.

Both coatings can fail due to abrasion or erosion. However, the type of failure is distinctly different in that Zebron failure is usually associated with delamination or substrate disbonding while the Inerta 160 failure is associated with random areas of corrosion through the coating. As illustrated by the results shown in Figure 5.5.5 Inerta 160 seems to be more ice resistant then Zebron. It can be seen that both coatings demonstrate greater bond strength with decreasing temperature, and as a function of both temperature and thickness Inerta 160 exhibits superior qualities.

The abrasion and adhesion properties of Inerta 160 and the low friction properties of Zebron could be combined into a coating system which utilises the best of these properties (Calabrese, 1980). Inerta 160 could be used in way of the waterline and in the icebreaking areas of the bow and stern, with Zebron applied below the icebelt. However, the need for a sophisticated coating below the icebelt has not been extensively demonstrated.

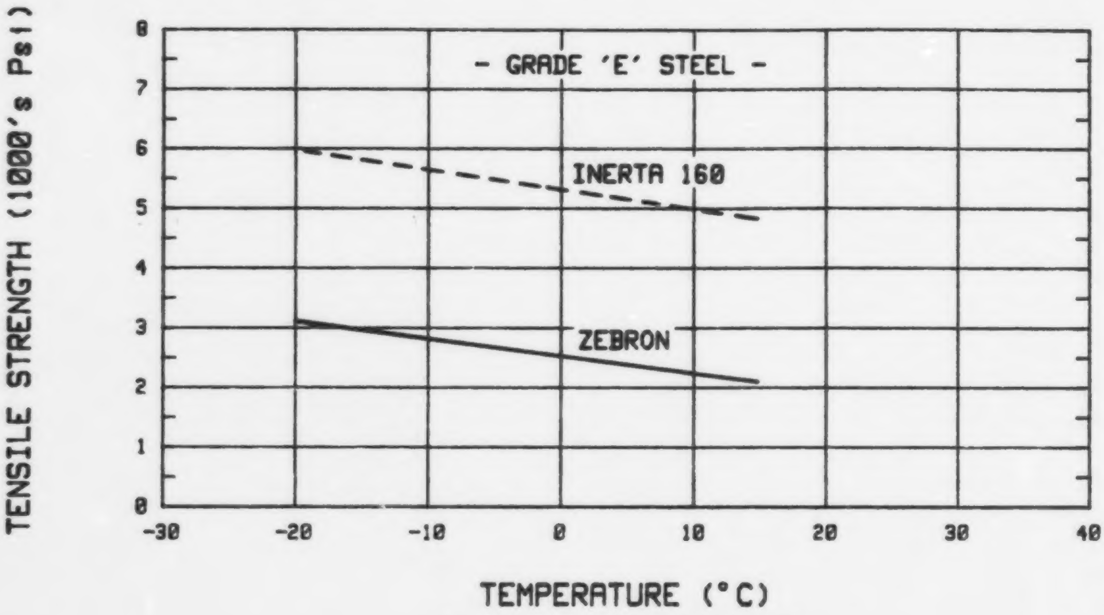
The choice of coatings, for ships which operate in the Arctic, depends on the mission of each ship. For topside areas chlorinated rubber paint is commonly used due to its cold temperature properties. However, this paint is also used on non-Arctic ships. Below the waterline the problems of hull abrasion and the search for a low friction coating have resulted in many research programmes. The outcome of these programmes is a better understanding of the nature of hull/ice interaction and coatings which appear to satisfy both requirements. Inerta 160 and Zebron, particularly Inerta 160, are now commonly used on icebreaking ships.

5.5.11 Accommodation

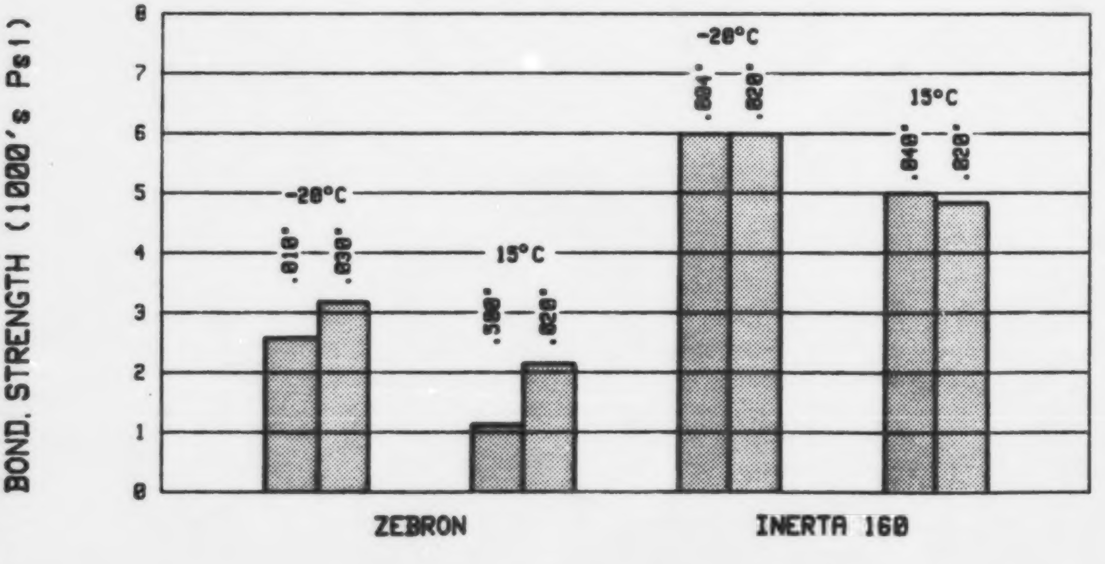
The accommodation of Arctic ships as with non-Arctic ships must be designed for the comfort of crew and for the effective operation of the ship.

FIGURE 5.5.5

ILLUSTRATION OF BOND STRENGTH FOR INERTA 160 AND ZEBRON



EFFECT OF TEMPERATURE



EFFECT OF COATING THICKNESS

An investigation of accommodation requirements (Melville, 1984) surveyed the opinions of Arctic seafarers on the accommodation facilities on the vessel in which they have sailed. The responses offer some insight on how the seafarer views accommodation related requirements.

- present cabin size is satisfactory (100% of responses).
- private cabins are important (100% of responses).
- isolation is the major aspect of the Arctic environment which affects the physical and psychological conditions (90% of responses).
- The period of continuous service should not exceed 2 months (60%) to 3 months (40% of responses).

The seafarer's response highlights noise, vibration and recreation facilities as areas of concern, but the other aspects, such as cabin size and climate, are acceptable as presently constructed.

Due to the hours of continuous darkness in which ships will operate, and to the hostile environment outside, decor and lighting may be an important part of maintaining a relaxed and hospitable environment inside the accommodation. On many modern vessels accommodation layout, decor and colour schemes are submitted to interior designers for their comments and input. The U.S.S.R. Arctic class ships pay particular attention to this aspect of accommodation design (Melville, 1984b). This study also made a number of recommendations on the recreation facilities.

Examples of the cabin floor area on recent Canadian Arctic ships are shown in Table 5.5.2. These values compare with $3.4m^2$ per person, required by the Canadian regulations. It can be seen that Canadian owners have built vessels which provide much larger private living spaces than are required by regulation. This appears to have resulted in a high degree of crew satisfaction.

Noise and vibration are probably the greatest sources of habitability problems onboard Arctic ships. The unusual levels of noise and vibrations, particularly on smaller vessels, are caused by propulsion machinery and ship/ice interaction. In many instances vibration produces noise due to the excitation of loose equipment and fittings in the ship or accommodation. The effects of noise and vibration on human beings has been the subject of considerable study and, although tolerance levels can vary from person to person, sufficient is known to propose limits.

The vibration effect has been quantified by the British Standards Institute as reduced comfort levels. These reduced comfort/time boundaries, plotted as acceleration versus frequency, are shown in Figure 5.5.6. It can be seen that the problems occur in the low frequency range, eg. once per second (1 Hz). At this frequency, which is excited during the icebreaking process, the reduced comfort/time limits relate to quite low levels of acceleration, eg. one hour at $0.27m/s^2$ or 0.03g.

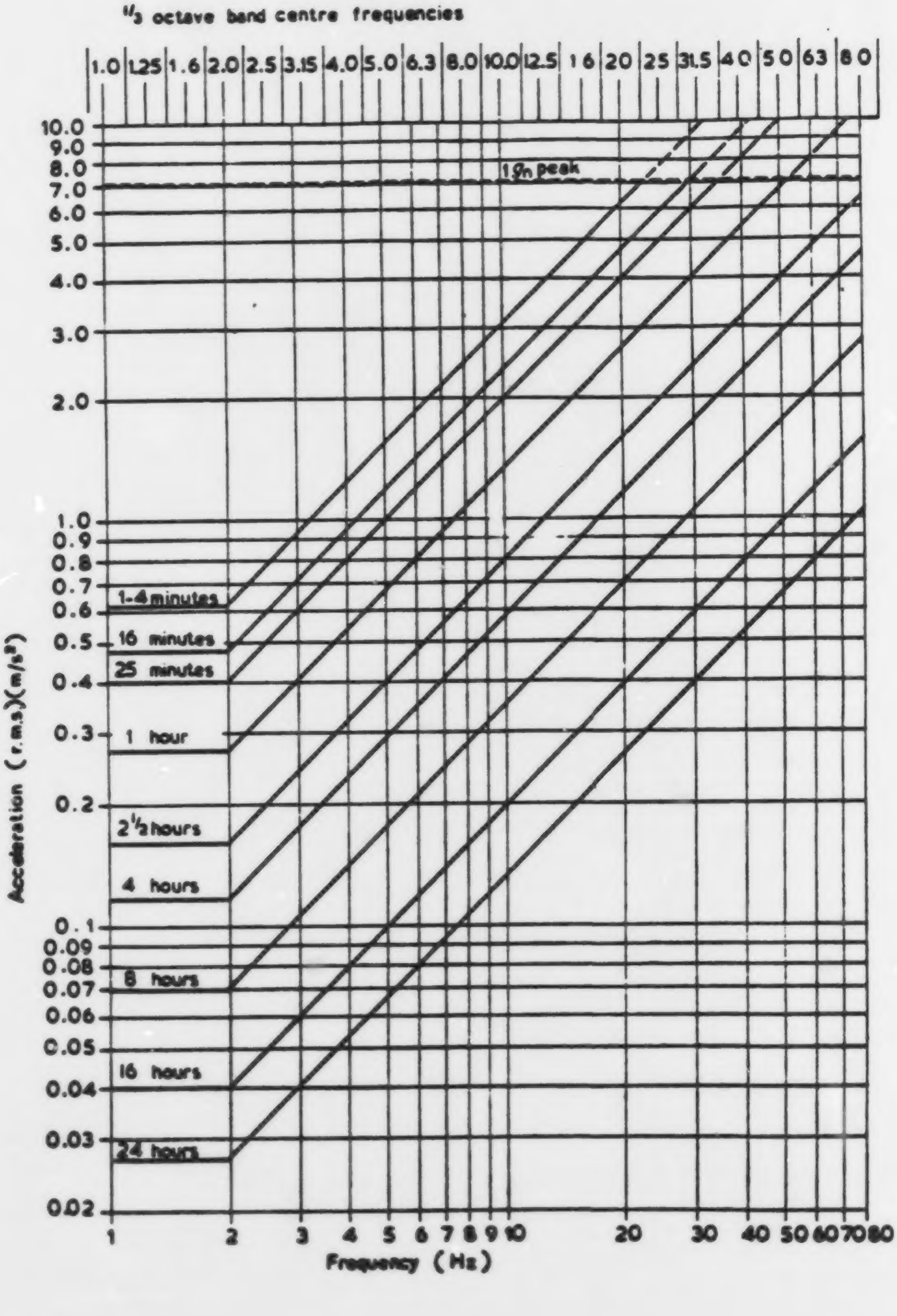
TABLE 5.5.2

CABIN FLOOR AREA ON RECENT CANADIAN ARCTIC SHIPS

SHIP	TYPE	OWNER	FLOOR SPACE (Sq. M. Per Person)
Arctic	Bulk Carrier (Class 4)	Canarctic Shipping Company, Limited	7.9
Arctic Shiko/ Seaforth Atlantic	Offshore Supply Vessel (Class 2)	Fednav Limited	6.5
Canmar Kigoriak	Ice Management Supply Vessel (Class 3)	Canmar	7.5
Terry Fox/Kalvik	Ice Management Supply Vessel (Class 3)	Beaudril	7.0

FIGURE 5.5.6

REDUCED COMFORT BOUNDARY OF VIBRATION VERTICAL AND HORIZONTAL



In Canada, the regulations which govern the accommodation standards of ships are a) the Crew Accommodation Regulations and b) The tow boat Accommodation Regulations, both made under the Canada Shipping Act. These regulations cover requirements for cabin space, bed size, heating, ventilation and recreation space. No consideration is given to interior decoration (design) or recreation room facilities.

Various national authorities have proposed or included noise standards in their statutory requirements. Some of these requirements are shown in Table 5.5.3.

The standards for climate control proposed by the Society Of Naval Architects and Marine Engineers are shown in Table 5.5.4. These standards have been recommended for Arctic ships (Melville, 1984b).

The accommodation facilities required on Arctic ships are in many ways similar to those on non-Arctic ships, although the severe climate of the Arctic does impose design requirements in regard to air temperature. These requirements will be reflected in such areas as insulation, climate systems and vibration control measures.

5.5.12 Information Deficiencies

The deficiencies in relation to general outfit and auxiliary systems cover a wide range of equipment and systems. Of most importance is the effect of ice on the requirements of steering gears. This is a subject of great concern to ship safety and should be given a high priority. Other areas of interest relate more to improvements in the practicality of the ship design from the operations viewpoint.

a) The deck machinery presently being used on Arctic ships has generally performed well. Experience has been gained with all of the major system types and, while there are specific benefits associated with each option, all appear to be technically acceptable. Special care must be taken with the choice of materials, hydraulic oil and lubricants, and with the protection of equipment against mechanical damage. Important aspects include:

  - the protection of deck equipment from icing and the design of de-icing systems.

  - the design of enclosed mooring flats where the working environment can be controlled, and the design of equipment shelters for the open deck.

  - the extent of which low temperature materials are necessary in deck equipment.

b) The mooring systems presently used on Arctic ships are similar to those on non-Arctic ships, and appear to have performed satisfactorily. However, consideration is now being given to enclosed mooring flats, strain gauging the mooring lines to measure forces acting on the ship, and using polyester as a material for the mooring

TABLE 5.5.3

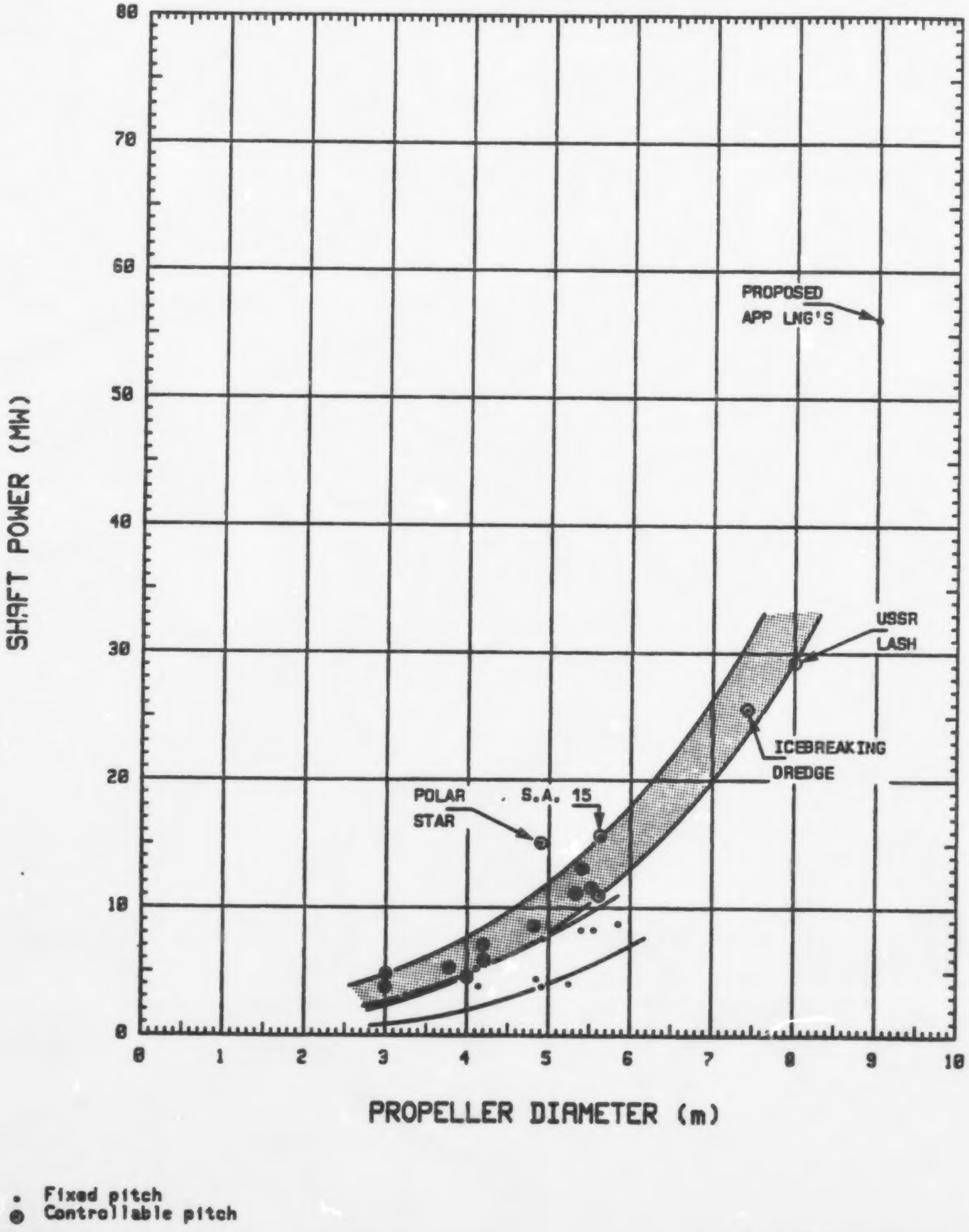
INTERNATIONAL SHIPBOARD NOISE STANDARDS

	UNITED KINGDOM dB(A)*	SWEDEN dB(A)	WEST GERMANY dB(A)	NORWAY dB(A)	DENMARK dB(A)
Machinery Space Without Control Room	90	85	90	90	90
Machinery Space With Control Room	110	100	110	110	110
Machinery Control Room	75	70	-	75	75
Working Areas On Deck And In Holds	90	65	-	-	-
Galley/Pantry	70	65	60	70	70
Wheelhouse	65	70	60	65	65
Radio Room	60	65	-	65	65
Office	65	-	60	65	65
Dayroom	65	65	60	60	65
Sleeping Cabin	60	-	65	70	70
Recreation Room	65	-	-	70	70

*dB(A) is a measurement of sound level in decibels which is representative of the ear's characteristics.

FIGURE 5.4.4

SHAFT POWER VERSUS PROPELLER DIAMETER FOR ICEBREAKING SHIPS



lines. The deficiencies in our knowledge of mooring systems relate mainly to the forces acting on the ship when moored in a variety of situations.

c) The design requirements for steering systems depend on the main dimensions and mission of the ship being considered. Ships which are long and deep are less likely to expose the rudder to severe ice interaction than short and shallow draft ships which may be used for aggressive ice management duties. Presently the design requirements which are enforced by the regulatory authorities are minimum standards.

Present practice may prove to be inadequate for High Arctic ships which must manoeuvre in multi-year ice. Only a greater understanding of the rudder/ice loads, and of how these loads are absorbed by the steering gear system, will give confidence that the present design requirements are still acceptable. Important aspects include:

i) The protection of the rudder from ice loads by innovative stern design, without detracting from the ship's hydrodynamic or icebreaking performance.

ii) The magnitude and effect of rudder/ice interaction on each element of the steering system.

iii) The way in which the steering system should be designed to accommodate the actual loads.

d) The efficient operation of sea inlet boxes is of great importance to Arctic ships. The main engine cooling system is normally fed directly from these boxes and any blockage will allow the cooling water temperature to rise above the permissable level. Solutions have been developed to maximise the efficiency of the sea inlet boxes, although these solutions are not always implemented on modern ships. The only major deficiency in the present understanding of how to deal with this problem is how the sea box grills of shallow draft ships may be kept free of slush ice.

e) Our present knowledge of probable icing conditions in the Arctic is very limited. Little attention has been given to the problems caused by the icing of deck equipment or of safety and evacuation systems. Anti-icing and de-icing systems must be developed to ensure personnel safety and to increase ship efficiency. Experiments should be designed and carried out to aid in developing anti-icing or de-icing systems which are practical for Arctic ships.

f) The choice of coatings, for ships which operate in the Arctic, depends on the mission of each ship. For topside areas, chlorinated rubber paint is commonly used due to its cold temperature properties. Below the waterline, the problems of hull abrasion and the search for a low friction coating have resulted in many research programmes. The outcome of these programmes is a better understanding of the nature of hull/ice interaction and, coatings which appear to satisfy both requirements. The deficiencies in our present knowledge of hull coatings and their application may be summarised as:

i) The location of hull areas where most of the ice impacts and abrasion occurs.

ii) The true hull/ice friction factors, and the operating conditons of the coating, in terms of load versus time and frequency.

iii) The cost benefits of installing the more expensive coatings required by the Arctic environment, as a function of the maintenance requirements.

g) The accommodation facilities required on Arctic ships are in many ways similar to those on non-Arctic ships, although the severe climate of the Arctic does impose design requirements in regard to air temperature. These requirements will be reflected in such areas as insulation, climate systems, and vibration control measures. The deficiencies in our present knowledge relate to how noise and vibration can be reduced effectively to acceptable levels.

6. POTENTIAL SHIPPING SYSTEMS

The focus for the review of the state-of-the-art of Arctic ship technology is currently known and available technology. To evaluate the important deficiencies which are present in this technology requires an assessment of future requirements. This section of the report provides the link between the deficiencies identified in the previous sections and the optimization and research sections which follow.

A seperate report was prepared entitled 'Probable Arctic Shipping Scenarios To The Year 2000' (Melville, 1986) which examined the future of Arctic shipping. This report concluded that opportunities for future vessels existed in three areas;

- oil and gas development
- mineral development
- government activities.

The first two areas of activity were reviewed in some detail with current and potential developers of these resources. There are only a few possible developments which could involve ships to transport the resource, and production from each will be dependent upon improved markets or government support.

The governments shipping activities in the Arctic are currently seasonal and are under the mandate of CCG. Their presence and activities are driven by the community requirements, commercial shipping activity and government policy, and the levels of community requirements and commercial activity will only change should resource development occur. Govenment policy can create demands such as the proposed Polar 8 which may lead to commercial development, but speculation in this area was beyond the scope of this study.

It is resource development which the report focused on because, if developed, some of these clearly will require new vessels to be constructed which will be more capable than existing vessels.

The study reviewed each of the potential projects and, by exercising some judgement, presented the 'most probable' Arctic shipping scenarios. These scenarios are described in Table 6.2.1 and in the following notes, the projects are divided into year-round and seasonal projects in Figures 6.2.1 and 6.2.2.

a) **Nanisivik (Lead Zinc)** - Existing tonnage should be sufficient to move the concentrate from the currently defined ore body at Nanisivik. Through further ongoing exploration the operator may locate sufficient reserves to produce beyond the five to eight years currently anticipated. Should this occur, existing vessels may have to be replaced.

TABLE 6.2.1

PROBABLE ARCTIC SHIPPING REQUIREMENTS

LOCATION	CARGO TYPE	ANNUAL VOLUME (TONNES)	SHIPPING SEASON CONTEMPLATED	PROJECT LIFE
MINERALS				
Nanisivik*	lead zinc	125-150,000	July - November	5-8 years
Polaris*	lead zinc	225-300,000	August - mid October	15 years+
Heninga Lake	zinc, copper gold, silver	125-175,000	June - mid October	10 years+
Izok Lake	lead zinc	200-300,000	mid July - mid October	15 years+
OIL AND GAS				
Bent Horn*	oil	13-70,000	August	3 years+
Beaufort Sea	oil	200-500,000	August - mid October	8 years+
	oil	50-500,000	July - November	8 years+
	oil	4-6 million	year-round	10 years+
	oil	1-1.5 million	year-round	10 years+
High Arctic	oil	2-2.5 million	year-round	20 years+
	gas	3-3.5 million	year-round	20 years+

* Operating Projects

b) **Polaris (Lead Zinc)** - With production expected from this property beyond the mid 1990's, it is anticipated that new vessels will be required to meet the shipping requirement. It is not expected that vessel size or types will be different than those which currently service the mine.

c) **Izok Lake (Zinc, Copper, Gold, Silver)** - Izok Lake is forecast to be the next mineral property to be developed. The lead and zinc concentrates from this property may be transported to the coast and shipped seasonally using a vessel similar in size and capability to the ARCTIC.

d) **Beninga Lake (Lead Zinc)** - The copper and zinc ore on this property also contains significant quantities of gold and silver. This ore may be moved to the west coast of Hudson Bay and then be transported south on barges to Churchill or east to Europe on deep sea vessels. This will be a seasonal operation and the small quantities of ore will not require the construction of new vessels.

e) **Bent Horn (Oil)** - The only oil presently being shipped from the Arctic is from Panarctic's Bent Horn well. The operator is currently shipping 100,000 bbls per year and expects to continue at that volume for the next few years. Although possible, it is unlikely that more than 500,000 bbls of oil will be shipped per year.

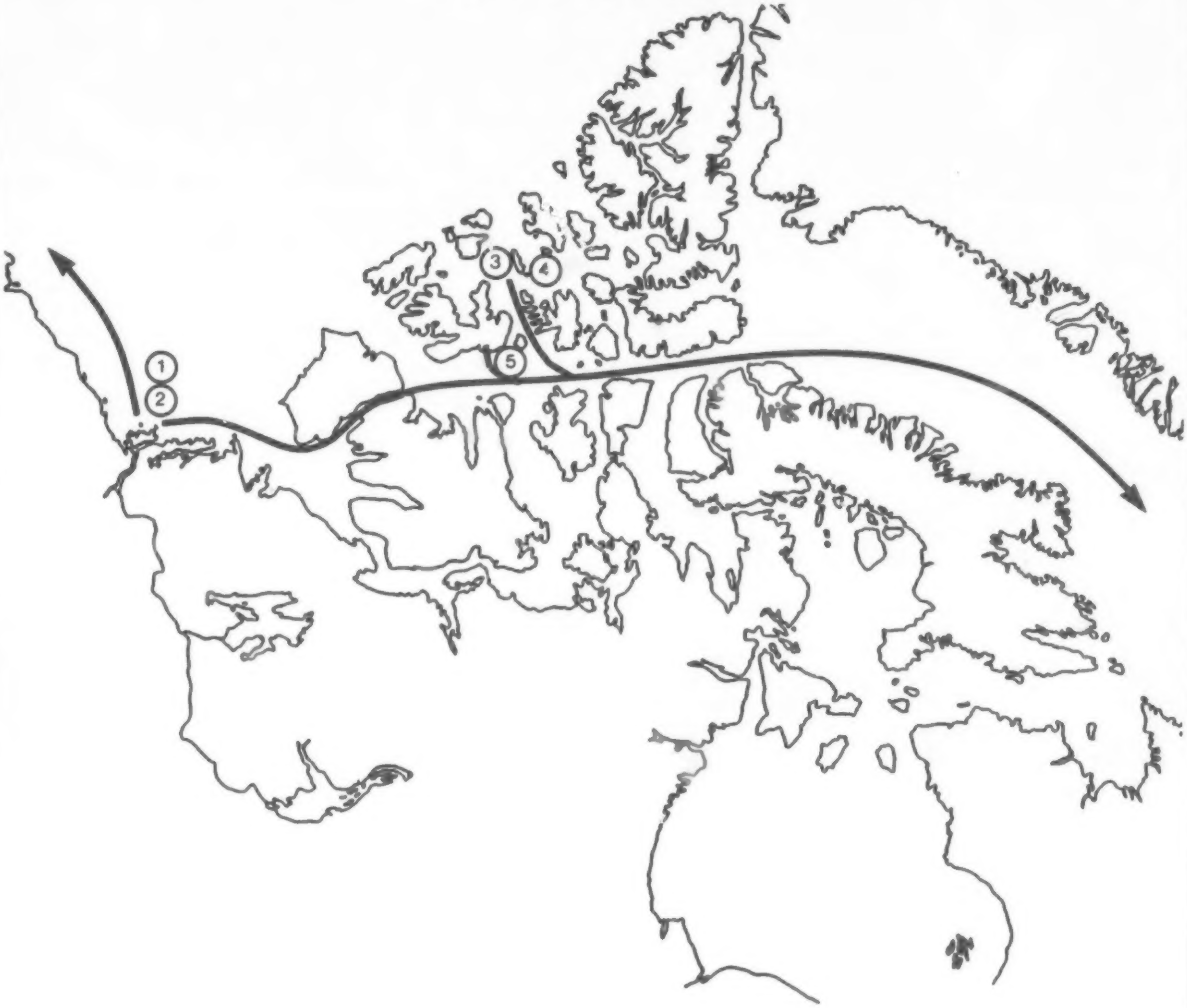
f) **Beaufort Sea (Oil)** - Small volumes of 200-500,000 tonnes can easily be produced and transported from the Beaufort Sea during the open water season. Any small scale open water shipping requirements can be handled by existing tonnage. Larger scale seasonal requirements may involve the use of ice class tankers or barges. Seasonal shipping systems which use new vessels or ice structured existing tonnage are feasible for moving up to 500,000 tonnes per year.

Should 100-300 million bbls of oil be produced offshore, a 50,000 dwt Arctic class vessel could be used to transport the oil year-round. A system using storage facilities in the Beaufort Sea could be used, or the Arctic class vessel could navigate to the ice edge for transshipment.

Should offshore oil be located in sufficient quantity to justify large scale development, 200,000 dwt vessels have been proposed for year-round operation. These vessels might be supplemented by ice class tankers or tranship their cargo to ice class vessels in Lancaster Sound. The system would be highly dependent on the quantity to be shipped and the tarrif available.

FIGURE 6.2.1

YEAR ROUND SHIPPING OPPORTUNITIES TO THE YEAR 2000



PROJECT	ICE CAPABILITY	VESSEL SIZE	SHIPS REQUIRED
BEAUFORT SEA OIL			
1. SMALL SCALE YEAR-ROUND	MULTI-YEAR	50,000 DWT	1
2. LARGE SCALE YEAR-ROUND	MULTI-YEAR	200,000 DWT	2+
HIGH ARCTIC OIL			
3. CISCO (SMALLER VESSELS)	MULTI-YEAR	100,000 DWT	2+
4. CISCO (LARGER VESSELS)	MULTI-YEAR	200,000 DWT	1+
HIGH ARCTIC GAS			
5. ARCTIC PILOT PROJECT	MULTI-YEAR	2 x 140,000 CU M	2+

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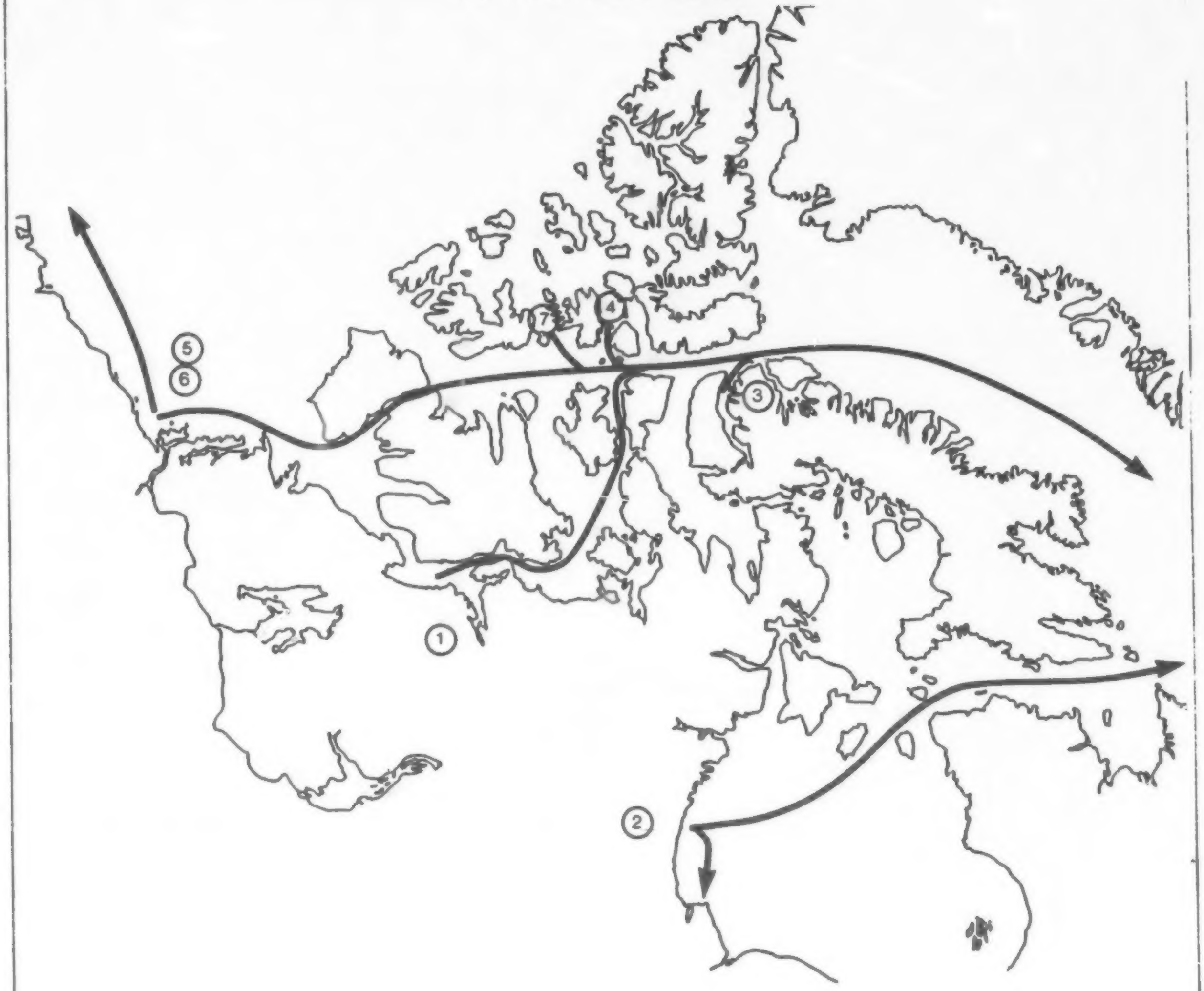
FIGURE 6.2.2

SEASONAL SHIPPING OPPORTUNITIES TO THE YEAR 2000



PROJECT	ICE CAPABILITY	VESSEL SIZE	SHIPS REQUIRED	SEASON
MINERAL PROPERTIES				
1. IZOK LAKE	FIRST YEAR	20-30,000 DWT	1+	AUG - OCT
2. HENINGA LAKE	FIRST YEAR	20-30,000 DWT	1+	JUN - DEC
3. NANISIVIK	FIRST YEAR	20-30,000 DWT	1+	JUL - NOV
4. POLARIS	FIRST YEAR	20-30,000 DWT	1+	AUG - OCT
BEAUFORT SEA OIL				
5. SEASONAL PRODUCTION	MINIMAL	20-50,000 DWT	1+	AUG - SEP
6. EXTENDED SEASONAL PRODUCTION	FIRST YEAR	20-50,000 DWT	1+	AUG - OCT
HIGH ARCTIC OIL				
7. BENT HORN	FIRST YEAR	20-30,000 DWT	1+	AUG

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g) **High Arctic (Oil)** - Two vessel sizes have been discussed for the year-round production of oil from the high Arctic, assuming similar production rates:

   - two 100,000 dwt Arctic class vessels,
   - one 200,000 dwt Arctic class vessel.

   Either of these vessels would be capable of year-round operation from the Lougheed Island area and could transport 2-2.5 million tonnes annually. The two ship system will be more costly but has the advantages of reliability and safety.

h) **Arctic Pilot Project (Gas)** - The APP is presently on hold until gas markets and pricing are more attractive to the developers. This project involved the use of two 140,000 cu m Arctic Class 7 ships to deliver 1.9 MM BCF of gas per year from Melville Island, NWT, to southern markets for a project life of 20 years. It is estimated that a six year start-up will be required to proceed with the project. Should world gas prices increase the project could proceed prior to the year 2000.

It can be seen that there are only a few probable projects and, for each one, there are only one or two configurations being considered by the project proponents. The major choice which must be made relates to the use of one large vessel or several smaller vessels. While it is quite likely that the one ship system will be more economic, the ship size will impose demands on the technology which in turn will reduce the system's reliability.

Considering the most probable projects, it is only the large scale Beaufort Sea oil project, the high Arctic oil project, and the Arctic Pilot Project which are large enough to require very large vessels. In each of these cases, 200,000 dwt oil tankers or 140,000 cu m LNG carriers (equivalent in size to a 200,000 dwt oil tanker) could be the preferred mode of transportation. The economics of using vessels of this size will undoubtedly be better than smaller vessels but the vessel size requires very high propulsion power and structural strength, raising questions of reliability.

Optimisation of the configuration of these systems is therefore complicated by issues of technology. It is not acceptable to look only at the economics of ships of various sizes and settle on the system with least overall cost, unless the evaluation can somehow include the economic effect of system downtime for ship repair. Risk and reliability models have been developed in other industries to take into consideration this very important issue, but these models in the shipping industry are in their infancy. Inevitably these models must rely on a database of accurate and reliable information. If no such information is available, as with Arctic ships, this element of system life cycle cost cannot be used.

The probable Arctic shipping scenarios described above lead to the conclusion that large Arctic ships may be required in the near future, and that the issues of Arctic ship technology which relate to ship size should be fully explored to determine where deficiencies in the present state of the art would limit the size of ship which could be built. Similarly, where optimisation of ship components can reduce the capital or operating costs, every effort should be made to understand the ramifications, particularly when the proposals would require components which are larger or radically different than has been previously constructed.

7. OPTIMISATION AND RECOMMENDED RESEARCH

7.1 Introduction

The review of Arctic ship technology contained in the preceeding sections addresses separately each aspect of designing and operating ships, recognising that there is a clear link between 'design' and 'operations', and between these and the environment. The ability to design ships for a given set of environmental conditions is seldom in doubt and similarly, although with less certainty, the expertise presently exists to operate ships year round.

These abilities relate to the size of the shipping system, the size of the system components, the locations to be served, the season of operation, and the ability to extrapolate safely and reliably from known technology. It has been demonstrated that the solution(s) to these problems of system configuration are changing with every breakthrough in technology and every extension of the operating season. Examples of this are the success of the Beaufort Sea vessels and the most recent success in the eastern Arctic of the ARCTIC.

The process of solving these shipping system and ship configuration problems can be referred to as 'optimisation'. Although the perception of the optimum solution is changing with experience, a particular shipping system will be tied to the understanding of Arctic ship technology at a point in time. Even recognising that limits may exist in the construction and operation of these ships, there are many options open which may greatly effect a project's overall economics. It is the search for the most economic yet safe and reliable system, considering the total mission profile, which can properly be referred to as optimisation.

It is also clear that shipping systems are planned many years ahead of the proposed operating period, placing on the designers and operators the additional burden of anticipating developments in design, manufacture, construction and operating capabilities. It is for this reason that a research programme should be initiated to explore all of the benefits and liabilities of solutions which would extend the present boundaries of these capabilities.

7.2 Optimisation

The optimisation of a ship's design can be pursued from several directions. An optimum design can be quite different depending on the importance given to the parameters which are subject to optimisation. For example, the parameters which can be used for optimisation include:

- open water performance,
- performance in level ice,
- minimum fuel consumption,
- minimum capital cost,

- minimum operating cost,
- minimum life cycle cost.

Several, if not all, of these parameters are in conflict. While it is possible to design the ship for any of the parameters, the combination of two or more will result in the need for compromise. Optimum open water performance cannot be obtained without sacrificing performance in ice and vice versa. Similarly, minimum fuel consumption and operating cost implies a design with low resistence in ice which leads to narrower breadth and increased length resulting in a higher capital cost. In fact, although these relationships are complex and should be fully considered, the two primary aspects which must be defined very early in the design process are:

- The mission profile and primary design requirements, including details of the voyage routes, seasons of operation, environmental conditions, preferred operating strategies in ice and open water, and any restrictions in regard to design details such as type of fuel, draft, manoeuvring capability, propulsion system type, etc.

- The major optimisation parameter, i.e. the aspect or combination of aspects at which the design must be aimed.

These considerations are very important but the latter is fundamental. For most commercial ships, perhaps unlike pure icebreakers, the most often used optimisation parameter is 'minimum life cycle cost'. This parameter reflects the overall cost efficiency of a vessel while ensuring that the ship can perform all of the functions for which it is intended. This is also the parameter which requires that the designer considers all of the design options which could lead to capital cost reductions but perhaps at the expense of reliability. Since the life cycle cost incorporates the cost of ship downtime it becomes important, if the optimum ship is to be obtained, to understand the impact of design options.

To focus on this issue of design options; if the optimisation parameter is life cycle cost, or even capital or operating cost, the optimisation process will lead the design towards reducing the construction and fuel costs. While there are other cost considerations, it is these which will have most impact on life cycle cost. Any design feature which can significantly improve these costs deserves to be carefully considered. The life cycle benefits can be great, in the order of hundreds of millions of dollars. The following are the major areas of the ship design where the selection of design requirements, or of a particular design option, can have most impact.

a) **Hull Structure** - The hull structure of Arctic ships, especially cargo ships is designed to meet the requirements of regulations and of any requirements imposed on the vessels by the mission profile. Due to the particular operation of a vessel the structural loads can vary over a wide range. As a result the weight, size, complexity, material type, and construction cost can also vary greatly.

As an example, in a recent major project the result of an inappropriate selection of bow loading when ramming multi-year ice was a ship which had a very high lightship weight. This was subsequently reduced by the choice a lower bow load. The reduction in steel cost was about $195 million. Translating into about $430 million over a 15 year project life.

While this may be an extreme example it does illustrate the importance of choosing appropriate design loads and the effect on life cycle costs of overall design. Considering also that this example occurred quite recently, it highlights the present lack of understanding of design loads, particularly for ships that would not wish to endure the most extreme loads possible but still must navigate in severe ice conditions year-round. Optimisation in relation to structure is therefore concerned with the designer/operator decision on how agressively the ship will be operated and on the assessment of design loads in that condition.

b) **Hull Form** - The hull form of Arctic ships is usually designed to operate as efficiently as possible in the maximum ice thickness defined by the mission profile. In the case of cargo ships, the need to operate efficiently in open water is also an important consideration. Depending on where the emphasis is placed, the ship's performance can be greatly influenced, as can the life cycle cost.

As an example, in a recent design, the hull form design parameter which was emphasised was icebreaking performance. The result was a ship which performed extremely well in ice but required 75,000 hp to operate at 19 knots in open water, 25,000 hp more than for a ship where thedesign had recognized the need for efficient all-round operation which had only a slightly poorer performance in ice. As two further examples, recently, the ARCTIC, through redesign of the bow, has achieved a great increase in icebreaking performance while at the same time obtaining better performance in open water. This was achieved with a bow design which took into account both aspects of the mission profile.

The benefits which can be obtained from a better understanding of hull form design can be calculated from reduced power requirements, considering the associated capital and fuel cost savings. Considering the recent success of the ARCTIC, and extrapolating the saving in power obtained on that ship to a larger vessel, a reduction in power from 100,000 hp to 60,000 hp could be obtained. After considering the capital and operating cost benefits which would result from this the reduction in capital cost would be about $40 million, and in life cycle cost about $135 million.

This leads to the conclusion that major savings are available if the hull form of Arctic vessels can be designed to perform well in both ice and open water. However, the importance of this aspect goes beyond the savings which are available due only to the capital and fuel costs. The ability to reduce the installed power will lead to smaller power plants, higher reliability, and less likelihood of expensive downtime.

c) **Propulsion** - The propulsion system of Arctic ships has traditionally been diesel electric with three shafts and fixed pitch propellers. This is still the preferred system for government owned icebreakers throughout the world, although the DC electric system is now giving way to AC systems. The trend with cargo ships, since the mid 1960's, has been to install diesel geared systems with one or two shafts and CP propellers (with or without nozzles). This trend is likely to continue with cargo ships due the great difference in capital and operating costs between electric and mechanical drive systems.

As an example, a recent design proposed to install a 112 MW mechanical drive propulsion system with two shafts, each of 56 MW, CP propellers and nozzles. The alternate electric system was of the AC-FFC-AC type dividing the power between three shafts and using open fixed pitch propellers. The capital cost difference between these systems was about $40 million. With the saving in fuel cost due to the more efficient mechanical system, the life cycle cost saving is about $105 million.

It should be remembered that only two mechanical drive propulsion systems have ever been commissioned for an icebreaking ship with a power level above 16.5 MW. These are the Soviet Lash vessel SEYMORPUT (now operating), and the Arctic dredge, which was never constructed. These systems are 29.42 MW and 27.5 MW per shaft respectively. It could equally be said that the highest power per shaft electric system is 16.65 MW installed on the Soviet LEONID BRESHNEV class of icebreaker. This places in perspective the lack of experience which exists for high power per shaft transmission systems.

This would lead to the conclusion that, although untried on icebreaking vessels, high power per shaft and mechanical transmission systems are desirable features. The benefits to be obtained from such systems are great, but the uncertainty which exists as to the system's reliability should be clarified.

The optimisation process described here is, in fact, more of an exercise in decision making. In each of the major areas of the ship's design selections must be made of either design conditions or system components. Irrespective of whether the process is called 'optimisation' or simply 'design', there exists the potential for large life cycle cost savings if the full extent of the state of the art is applied and if the state of the art is expanded in several key areas.

7.3 Recommended Research

7.3.1 Rationale

It can be seen from the text of this state-of-the-art review that the level of understanding of the requirements, which are imposed on ships when operating in the Arctic, has increased tremendously over the last few years. The historical data on existing ships, presented in section two, illustrates the number of icebreaking vessels and offers some insight into how the technology is changing with time. When read in association with the detailed technology review sections it can be seen that the years between the mid 1970's and mid 1980's have produced a wealth of full scale data and a number of innovations.

It is equally clear that, although much has been achieved, much is still to be done. There are many areas of the technology where very little is known. For example: the unpredictability of the ice cover from year to year; the navigability of ships in a range of ice conditions; the forces acting on the structure of ships in ice; the propulsion requirements which will ensure safe and economic progress; and the reliability of several propulsion systems which may offer economic benefits.

When these deficiencies are placed in the context of the most important single parameter for commercial Arctic shipping, economics, it is possible for them to be priorised ie, organised in terms of timeframe and the resources which should be allocated towards finding solutions. It may not be possible to reduce everything easily to economic terms. Some problems relate more to practical operational concerns, which could be solved by appropriate design if sufficient information were available on the problem. These deficiencies can also be priorised on the basis of, for example, ship or personnel safety.

The following text presents a programme of recommended research which is focussed on the areas of Arctic ship technology where: (a) dramatic improvements in transportation efficiency are possible, and (b) improvements in the safety and practicality of Arctic shipping are possible. The presentation is subdivided into the same aspects of Arctic ship technology which have been reviewed and presented in the preceeding section of this report:

- environment,
- ship operation, and
- ship design.

In compiling the list of recommended research projects, the information deficiencies presented in each section have been reviewed. These deficiencies have been assessed against the criteria described above, and those items of research which would be of most benefit to the future development of Arctic shipping and which qualify as 'Research' have been retained. The following presentation of recommended research is therefore made up of the most important deficiencies.

The format is to:

- Preface each area of technology with some introductory comments designed to link the subsequent research list to the review in the main report section.
- Present a figure which briefly describes the research items, with an indication of timeframe, in terms of a five year horizon, and approximate cost.
- Present a list of the research items, more fully described, with an indication of approximate cost and level of priority.

The priority ratings are; 'high', 'medium', and 'low'. This artifice is simply a means to generally categorise the items into those which should receive immediate attention, those which may be important but which are not required immediately, and those which are of less importance in the short term.

7.3.2 Environment

The review of environmental conditions in the Arctic was subdivided into; 'ice', 'oceanography', 'meteorology', and 'route specific environmental criteria'. In each of these areas there is a database available, the size and validity of which is quite varied. For example, data on meteorology is substantial although not complete, and on oceanography and ice is quite incomplete. It is therfore to be expected that, when compiling a set of route specific data, deficiencies will be highlighted.

The highest priority should be given to research programmes which focus on the effect of the environment on ship design and operations. A lesser pricrity should be assigned to deficiencies, although they must still be eliminated, which will have a less important effect on the commercial or practical development of Arctic shipping.

Based on the review of Arctic ship technology, as it may be effected by the environment, a number of research or investigative projects are recommended. These are described in the following notes with an estimate of cost and an indication of priority. To more graphically illustrate the proposed programme, the projects are listed in Figure 7.3.1, with an indication of the timeframe for completion and cost.

a) Experience on board the M.V. ARCTIC has shown that the properties of both first year and old ice undergo a dramatic change during the warm spring and summer period. Investigations should be undertaken on the changing properties of ice during this period.

FIGURE 7.3.1

PROPOSED ENVIRONMENTAL RESEARCH

PROPOSED RESEARCH	YEARS 1	2	3	4	5	TOTAL COST (000,s)
a) Changing properties of ice.	----	----	----	----	----	500
b) Ice regimes studies.	----	----	----	----	----	500
c) Demonstration voyages/ice studies related directly to ship performance.	----	----	----	----	----	1,000
d) Geographic distribution of icebergs in Baffin Bay.	----	----	----	----	----	250
e) Variability of old ice movements.	----	----	----	----	----	250
f) Mechanical properties of ice as it relates to design criteria.		----	----			100
g) Investigation of the factors which influence good and bad ice years.				----	----	200
h) Ridge data analysis.				----	----	150
					TOTAL	2,950

Included with this investigation should be an analysis of where decayed ice is more likely and, conversely, less likely to be encountered.

In addition, the properties of ice of all ages at different times of the year should be quantified. These measured properties should be collected in a manner such that they can be related directly to ship performance and structural requirements.

Approximate Cost - $500,000
Priority - High

b) There are many facets of ice regimes which are not presently well understood. The development of accurate models on ice motion prediction will require a much better data set on the ice regimes of the high Arctic. Continued research on ice regimes should be undertaken and should focus on the following deficiencies;

- an understanding of the factors which influence the consolidation and subsequent fracture of ice regimes, particularly in Lancaster Sound,
- factors which influence the location, development and variability of ice pressures and rubbling,
- ice motion and floe dynamics statistics should continue to be collected over the high Arctic.

Approximate Cost - $500,000
Priority - High

c) The findings of most ice regime studies do not directly relate to ship performance. Data collected on ice regimes should relate directly to ship performance and this should be undertaken by test probes and performance evaluation of icebreaking vessels insitu. This should be accomplished by undertaking demonstration projects and dedicated research voyages into ice regimes where data on ship performance do not presently exist or are inadequate.

Approximate Cost - $1,000,000
Priority - High

d) The geographic distribution of glacial ice hazards in the eastern Canadian Arctic are not well understood. Research efforts should focus on quantifying the distribution of icebergs within Baffin Bay to highlight areas of above average and below average distribution. In addition, the seasonal and annual variation of iceberg population should be quantified to investigate the effect, if any, of seasonal and annual climatic fluctuations of iceberg production and decay. The most effective method of collecting these types of data are through the continuation and expansion of shipboard observations. The collection of this data will aid in the development of iceberg distribution models and optimum shipboard routing decisions.

Approximate Cost - $250,000
Priority - Medium

e) The movement of old ice out of Nares Strait into northern Baffin Bay poses a significant threat to navigation at the entrance to Lancaster Sound. Little is known about the pattern and variability of this old ice movement and, consequently, this should be investigated and documented.

Approximate Cost - $250,000
Priority - Medium

f) A reasonable amount of measured ice strength data are available for the Arctic regions, but in most cases the data from different times and locations cannot easily be compared or used to derive reliable design criteria because the results are highly dependent on test conditions. Much more effort is required to establish the conditions under which ice mechanical properties should be measured to develop design criteria.

Approximate Cost - $100,000
Priority - Medium

g) The ice regimes of Baffin Bay, the high Arctic islands and the Beaufort Sea appear to operate independently. A good ice year in one location may occur at the same time as a bad ice year in another. The factors which influence the creation of a good or bad ice year should be investigated to ascertain if predictive models and long range forecasting is feasible.

Approximate Cost - $200,000
Priority - Low

h) Thousands of useful measurements of ice ridging taken by the AES laser profilometer, have not been analyzed or published. Data from most sources including AES, U.S. Navy and other sources, provide misleading information because the ice regimes associated with the ridge data are not defined. The available data should be analysed to present comprehensive information on ridges in a way which is most useful to ship operators and designers.

Approximate Cost - $150,000
Priority - Low

7.3.3 Ship Operation

The review of ship operation in the Arctic was subdivided into; 'safety', 'navigation', and 'communications'. In each of these areas there is information available on the systems, equipment and methods used. It is only in the last ten years that ships have begun to operate in the Canadian Arctic during winter months and in areas of severe ice conditions. The quality of available information therefore depends heavily on experience. Although the old problems of safety, navigation and communications are now being more carefully considered, and substantial resources are being used, many important deficiencies exist.

The highest priority should be given to research programmes which focus on increasing the safety and navigability of ships in areas and during seasons which relate directly to the economic viability of future Arctic shipping systems. While issues of ship and personnel safety are paramount, the advances in Arctic ship operation which have been most dramatic are those associated with the detection and avoidance of hazardous ice and the safe and economic routing of ships through previously impenetrable areas. It is these areas of ship operation technology which will open the Arctic to year round shipping, and it is here that the future resources must be concentrated.

A lesser priority should be assigned to deficiencies, although they must still be eliminated, which will have a less important effect on the commercial or practical development of Arctic shipping.

A number of research or investigative projects are recommended. These projects are described in the following notes, with an estimate of cost and an indication of priority. The projects are subdivided into the categories of 'safety', 'navigation', and 'communications'. To more graphically illustrate the proposed programme, the projects are listed in Figure 7.3.2, with an indication of the timeframe for completion and cost. In this table, the priority allocated to each project is reflected in the timeframe within which the project should be completed.

7.3.3.1 Safety

The deficiencies in relation to ship and personnel safety are confined to the requirements placed on the vessel, equipment and personnel in the event of a fire and/or ship abandonment situations. Since personnel safety is involved the following projects are all considered to be high priority.

a) The unique nature of the Arctic environment requires that special consideration be given to crew survival. The present regulations provide only for ship abandonment in open water with no special consideration given to the Arctic. Research has been performed recently which identifies shortfalls of the equipment presently carried on board ship, and which recommends further development and testing of survival equipment and supplies. The recommended programme of research includes:

   i) A programme of carefully designed and supervised field tests should be carried out, of prototype and other available lifeboats and liferafts, to assess their suitability for Arctic use and to validate manufacturers claims. The lifeboats and liferafts should be tested in

FIGURE 7.3.2

PROPOSED SHIP OPERATIONS RESEARCH

PROPOSED RESEARCH	YEARS					TOTAL COST (000,s)
	1	2	3	4	5	
Safety						
a) Lifesaving research:						
i) Field tests on lifesaving equipment in winter conditions.	----	----				250
ii) Field tests on personnel survival equipment and supplies in winter conditions.	----	----				200
iii) Field tests to assess the means of evacuation from Arctic ships.	----	----				150
b) Development of an Arctic survival training programme.	----	----				200
c) Field tests of shipboard firefighting equipment in very cold conditions.	----	----				250
Navigation						
a) Further development of SINSS.	----	----				500
b) Collection of radar data for small targets in sea clutter.	----	----				500
c) Detection of hazardous ice by use of improved searchlights or other light sources.			----	----		100
d) Field programmes to collect data for the further development of iceberg detection Sonars.			----	----		1,250
Communications						
a) Development of the capability to access the Anik D satillite.				----	----	500
b) Field testing of an HF modem.				----	----	75
					TOTAL	3,975

different ice conditions arising from which may be developed an Arctic class of lifeboat and liferaft.

Approximate cost - $250,000
Priority - High

ii) A programme of field tests should be pursued to assess the usefulness and requirements for more approppriate personnel survival equipment, including:

- prototype and existing Arctic tents,
- prototype and existing sleeping bags,
- prototype and existing liferafts,
- insulated clothing,
- heatpaks, stoves and lanterns,
- provision pack,
- medical supplies.

Approximate cost - $200,000
Priority - High

iii) A set of field tests, supported by investigations, should be pursued to assess the means of evacuation of personnel and survival equipment onto the ice, and methods of transportation of the equipment away from the ship.

Approximate Cost - $150,000
Priority - High

b) Firefighting systems on Arctic ships must be carefully designed to ensure efficient operation in extreme cold air temperatures. Some systems such as dry chemical powders are not affected by these extremes but the water, foam, and to some extent the gaseous systems, are adversely affected. The effectiveness of each of these systems has yet to be demonstrated during a major fire on board an Arctic ship. Demonstrations should be planned and carried out in extremely cold conditions on board Arctic ships. The results should be documented and used as guidance for and for review of regulatory requirements.

Approximate Cost - $250,000
Priority - High

7.3.3.2 Navigation

The deficiencies in relation to ship navigation relate mainly to the lack of ability to detect ice and to understand the nature of the ice cover ahead of the ship. The successful navigation through areas of severe ice cover has been demonstrated with the aid of remotely sensing systems. However, this work is very much in the development stage and must be completed to secure the full benefits.

a) SINSS has proven to be a most valuable tool, however, the system requires operational assessment and fine tuning under winter conditions. The areas requiring improvement are:

- utility of the METEOR APT Satellite images.
- utility of ice forecasting services.
- improved weather data acquisition
- improved soft copy downlink systems.
- improved high speed computer manipulated and enhanced marine radar displays.

Approximate cost - $500,000
Priority - High

b) In order to improve marine radar detection techniques a data collection programme to obtain radar data for small ice targets in sea clutter is necessary. In addition, investigations into data processing techniques which show promise for increasing signal-to-noise ratio and signal to clutter ratios should be continued.

Approximate cost - $500,000
Priority - High

c) It is unlikely that electronic sensors will ever fully replace the visual detection of hazardous ice, in the close tactical sense, therefore, it is most important that continued research be carried out to improve searchlights or other light sources. The present difficulty in distinguishing between ice types when using searchlights, should be examined and solutions sought.

Approximate cost - $100,000
Priority - Medium

d) Field programmes are necessary in order to support and extend present knowledge regarding fundamental properties of acoustic propagation in Arctic waters. Important here are investigations into the frequency dependence of target strength and in the signal to noise aspects of various transducer configurations and installations. Propagation characteristics under ice also demands attention. From a theoretical point of view some research into the statistical nature of sonar echoes and their relationship with radar echoes from the same target is thought to be important.

Of more immediate concern to the design of a suitable sonar for ice hazard detection is the hardware problems associated with the deployment of a transducer assembly within the bow area of the vessel. In this respect the positioning and 'look direction' of a sonar transducer would have to be identified and the beam pattern and scanning rates defined.

Further investigation into ship and ice generated noise is also desireable as noise parameters are necessary in the design of an optimal detector.

Approximate cost - $1,250,000
Priority - High

7.3.3.3 Communications

The deficiencies in relation to communications relate to the improvement of ship to shore contact, and to the transmission of data to and from the ship.

a) As an interim solution to communications problems in the Arctic, a project aimed at enabling a ship to access the Anik D system should be carried out. The major problem will be the development of a suitable antenna and stabilization platform.

   Approximate cost - Unknown
   Priority - Low

b) Reliability testing in the field of an HF modem and channel evaluation system is required.

   Approximate cost - $75,000
   Priority - Low

7.3.4 Ship Design

The review of Arctic ship design was subdivided into; 'structures', 'hull form design and performance', 'propulsion', and 'general outfit and auxiliary systems'. In each of these areas there is information available on the equipment, systems, and methodologies used. Over the last ten years, in the Beaufort Sea and eastern Arctic, there has been a surge of activity resulting in important advances in the state of the art. While many advances have been made, the recent experience has shown that many important deficiencies still exist.

The highest priority should be given to research programmes which focus on increasing ship safety and improving the economics of Arctic shipping systems. Deficiencies in the area of hull structures are critical for safety and economics. This is also true for propulsion deficiencies. The effort which is required in the area of hull design and performance assessment is perhaps the most critical, since it is in this area that advances in navigability, maneouvring, and powering will improve the overall capability of an Arctic ship.

A lesser priority should be assigned to deficiencies, although they should still be eliminated, which will have a less important effect on the commercial or practical development of Arctic shipping.

FIGURE 7.3.3

PROPOSED HULL STRUCTURE RESEARCH

PROPOSED RESEARCH	YEARS 1	2	3	4	5	TOTAL COST (000,s)
a) Development of a methodology for plate design.	-----	-----				250
b) Develop a full understanding of framing behavior under ice loads and standardise the design methods.	-----	-----				250
c) Hull girder research:						
i) Field tests onboard Arctic ships.	-----	-----	-----	-----	-----	1,000
ii) Field tests to measure the ice response to ramming.			-----	-----		500
iii) Physical model testing of ship/ice interaction during ramming.			-----	-----		250
d) Development of fracture toughness criteria.			-----	-----		200
e) Field tests to validate the math modelling of the relationship between the air, water and structural temperatures.					-----	100
f) Relationship between the fracture toughness and strain rate of steel.					-----	150
g) Optimisation of weld metal material.					-----	150
					TOTAL	2,850

A number of research or investigative projects are recommended. These projects are described in the following notes, with an estimate of cost and a indication of priority. The projects are subdivided into the categories of 'structures', 'hull form design and performance', 'propulsion', and'general outfit and auxiliary systems'.

7.3.4.1 Structure

The deficiencies in relation to ship's structures relate to the loads to which the structure must be designed, and the materials which should be used. The lack of design load data is the most important deficiency, and should be the highest priority. This is reflected in the present high level of research activity in this area. To more graphically illustrate the proposed programme, the projects are listed in Figure 7.3.3 with an indication of the timeframe for completion and cost. In these tables, the priority allocated to each project is reflected in the timeframe within which the project should be completed.

a) To update plate design methodology it is necessary to establish realistic loading for multi-year ice and to account for the actual strength mechanisms. The designer or regulator must decide on the design condition (i.e., percent of permanent set) and the design life. If the design condition for the plating is to be a permanent set of more than three percent of the frame spacing, then membrane action must be the design behaviour.

   The best currently available plate strength formula is by Ratzlaff and Kennedy. This approach, among others, should be examined as a way of improving design methods. In addition, the effect of aspect ratio, and load reduction due to plastic behaviour is not well understood, especially in thick plates.

   Approximate Cost - $250,000
   Priority - High

b) Framing may also be designed plastically, except that shear is likely to be the critical stress. Some analysis of buckling and tripping has been performed, but has not yet become standardized in the design spiral. The complexity of possible framing arrangements compared to plating, does not permit a general behavioural diagram. Investigations of plastic or buckling response require sophisticated finite element programs such as ANSYS, ABACUS, ADINA or NASTRAN.

   A concerted effort should be made to understand the complete behaviour of framing under ice loads and standardise the design methods.

   Approximate Cost - $250,000
   Priority - High

c) The hull girder loads which may be encountered by existing or future ships are still uncertain and should by the subject of a research programme. The information base which is available covers only a few Arctic ships and of those only two, ARCTIC and MANHATTAN, provide data which applies to high L/D ships. This problem may be addressed in a number of ways:

   i) A long term programme of full scale stress measurements on existing Arctic ships will create a data base of information, which will guide the designer, operator and regulator.

      Approximate Cost - $1,000,000
      Priority - High

   ii) The numerical modeling of ship/ice interaction during ramming requires an accurate model of ice behaviour. The existing numerical models do not deal effectively with this requirement. The behaviour of ice under load must be investigated to improve the predictive capability of these models. Full scale measurement of ice response to ramming may be the only reliable way to obtain the data.

      Approximate Cost - $500,000
      Priority - Medium

   iii) The physical modeling of ship/ice interaction during ramming requires the ice to behave similarly at model scale and full scale. The ability to simulate the full scale response of the ice must be developed.

      Approximate Cost - $250,000
      Priority - Medium

d) Investigation is required on fracture toughness criteria that are economic to apply. The criteria should incorporate the effects of temperature, stress level, thickness and loading rate. In support of this work it may be necessary to systematically evaluate the presence of cracks on Arctic vessels.

   Approximate Cost - $200,000
   Priority - Medium

e) Experimental work is required in which the air and sea temperature is correlated with temperatures in the structure. A two-pronged approach could be used in which results from full scale experimental programmes are used to validate and/or calibrate numerical approaches.

   Approximate Cost - $100,000
   Priority - Low

f) The sensitivity of fracture behaviour of steel to strain rate has been noted. Although some data has been gathered, further data is required to establish the spectrum of strain rates experienced by Arctic vessels.

Approximate Cost - $150,000
Priority - Low

g) The problem of weld corrosion is the subject of current research and this effort should continue. Past research has indicated that the chemical composition can be adjusted to yield favourable properties, but often at the cost of reduced toughness.

Approximate Cost - $150,000
Priority - Low

7.3.4.2 Hull Design and Performance

The deficiencies in relation to hull form design and performance are in the two areas of optimising the shape of icebreaking ships and in predicting accurately the performance in a range of ice conditions. The benefits which can result from research in this area are substantial and can greatly influence the economic viability of future Arctic shipping systems. To more graphically illustrate the proposed programme, the projects are listed in Figure 7.3.4 with an indication of the timeframe for completion and cost.

a) There is a need for verification of the fundamental assumptions usually made in theoretical level ice prediction models so that the proper breakdown of resistance components can be made by source, i.e., the absolute value or percentage attributable to breaking, submerging and clearing of the ice.

Approximate Cost - $250,000
Priority - High

b) An empivical level ice performance prediction capability should be developed based on the known full scale performance of icebreaking ships. The international database is substantial but disorganised and presently unsuitable for use in this manner. The known performance must be related to hull form and size and to the predicted performance based on model tests. Model tests may then be conducted on intermediate hull forms to complete the family of performance data which can be used for interpolation or extrapolation to make accurate predictions for future ships.

Approximate Cost - $500,000
Priority - High

FIGURE 7.3.4

PROPOSED HULL DESIGN AND PERFORMANCE RESEARCH

PROPOSED RESEARCH	YEARS 1	2	3	4	5	TOTAL COST (000,s)
a) Breakdown of the components of icebreaking resistance.	----------	----------				250
b) Development of an empirical level ice performance prediction system.	----------	----------				500
c) Development of hull design optimisation methodology.	----------	----------				500
d) Improvement in the scaling of model ice characteristics.	----------	----------				150
e) Development of a model ice strength indexer and a procedure to relate the indexed strength to hull shape.	----------					150
f) Field tests to measure full scale friction forces and a model test programme to simulate those forces.	----------	----------				200
g) Determine the difference between the hydrodynamic forces in clear water and in ice.	----------					150
h) Analysis of the available full scale data on ramming for various ships.		----------	----------			100
i) Development of an understanding of the performance of ships in ridges.		----------	----------			250
j) Development of a modified towing post for use during resistance or 'English' style propulsion model tests.			----------	----------		100
					TOTAL	2,350

c) The optimum hull form for Arctic ship depends on the ship's mission profile and, to an extent, on the cost of construction. The search for an optimum hull design should continue, learning from the experience of the last ten years. A programme of hull design optimisation should be encouraged, aimed at developing a methodology for application to a range of ships.

Approximate Cost - $500,000
Priority - High

d) The present inability of model ice to correctly simulate the breaking patterns and strength of the ice leads to uncertainty when using model tests to predict the performance of ships. Although much research has been completed in this area, and progress is being made, the problems are far from being solved. Some of the most recent work has highlighted the inability of model basin tests to accurately simulate full scale.

A programme of research should be pursued to improve the scaling of model ice characteristics, particularly in regard to the prediction of ship performance.

Approximate Cost - $150,000
Priority - High

e) An improved procedure is required for monitoring model ice strength parameters in the same time frame and at the same speed as the ship model is being run. This procedure would relate more accurately the ice strength to the model shape, and make adjustments for the effect of shape on the model test results.

Approximate Cost - $150,000
Priority - High

f) The present understanding is poor on the effects and importance of friction on the results of model tests. The important aspects of this problem relate to both full scale and model scale friction. Present techniques attempt to either simulate correctly the friction coefficient, or run the tests at a nominal value and correct the results for the type of ship being tested ie, new or old.

A programme of research should be initiated to determine at full scale the magnitude of the friction forces and, at model scale, to simulate those forces.

Approximate costs - $200,000
Priority - High

g) Recent work on the hydrodynamics of model ships in ice has shown that the thrust reduction factor may not be properly simulated. These recent results have indicated discrepancies of up to 400 percent of the value which is obtained during clear water model tests. This difference has a large impact on the prediction of performance at full scale and therefore on the power which may be installed as a result of those tests.

A programme of research should be initiated to determine the difference between the hydrodynamic forces measured at model scale in clear water and in ice.

Approximate cost - $150,000
Priority - High

h) An analysis of existing data on the level ice ramming capability of icebreaking ships will be a starting point from which a better understanding may be gained of overall ramming performance. The available data should be assembled and, along with details of the ships, used to begin the development of a ship ramming performance prediction model.

Approximate Cost - $100,000
Priority - Medium

i) Ship performance in ridges has received very little attention in the past. Ridges are much more complicated ice features than level ice and, despite the many years of work on the latter, there is still no accurate model for performance prediction. The areas which require further investigation include:

- ship/ridge interaction mechanisms,
- pressure ridges, failure modes,
- development of simplified algorithms for prediction of ship performance,
- development of methods for modelling pressure ridges at model scale.

Approximate Cost - $250,000
Priority - Medium

j) Experience of model resistance and 'English style' self propulsion tests, during which the model is restrained in the fore and aft direction, has demonstrated that the data are influenced by vibration of the carriage and towing post. Particularly, the towing post has been identified as the major source of interference. It should be the objective of model test to simulate to the greatest extent possible the true forces acting on the ship at full scale. Presently this is the true forces acting on the ship at full scale. Presently this is not possible. A programme of experiments should be performed, resulting in a modified towing post for resistance tests.

Approximate cost - $100,000
Priority - Medium

7.3.4.3 Propulsion

The deficiencies in relation to propulsion are in the areas of the design loads which may be expected, the methodologies for designing system components to these loads, and the limitations of present manufacturing technology. It is these areas which govern the size and therefore the economics of propulsion machinery and, as a result, will have most influence on the viability of future Arctic shipping systems. To more graphicaly illustrate the proposed programme, the projects are listed in Figure 7.3.5 with an indication of the timeframe for completion and cost.

a) At present, CASPPR and the rules of the classification societies use the Finnish-Swedish ice class rule formula as the model to calculate the shafting diameter for Arctic class ships. This formula is empirical in nature and developed to suit the needs of relatively small and less powerful ships.

The various rules used to calculate shaft size be specially should be examined for various sizes and classes of ships and for various propeller weights. Using the calculated shaft size and the assumed propeller weight, the shafting principal stresses should be determined using agreed ice overload factors to ensure that sufficient margins or safety factors are provided by the formulas.

Approximate Cost - $75,000
Priority - High

b) Medium speed diesel engines are technically the least favourable engine for Arctic service due to poor over-torque characteristics and the potential for overload when ingesting very cold air. There is also a certain amount of evidence to suggest that engine pistons and liners may experience a higher rate of wear when operating in the Arctic than in more temperate waters.

A detailed study should be made of the operating problems associated with diesel engines in Arctic ships. The study should include theoretical considerations of the problems encountered when ingesting cold air and the various systems proposed to overcome this problem. Also, operating experience should be investigated to ascertain true wear rates of the engines to be compared with wear rates of similar engines fitted to open water ships.

Approximate Cost - $75,000
Priority - High

c) Ships which operate in some areas of the Arctic will experience icing at some times in the year. Even though icing of the ship's structure may not occur, icing of the engine room and engine intakes may take place. This is due to the accelerated air flow caused by these intakes.

FIGURE 7.3.5

PROPOSED PROPULSION RESEARCH

PROPOSED RESEARCH	YEARS					TOTAL COST (000,s)
	1	2	3	4	5	
a) Development of propeller shafting design methodology.	----					75
b) A study of the operating problems of diesel engines in the Arctic.	----					75
c) A study to assess the problems of burning heavy fuel in the Arctic.	----					50
d) Investigate the icing of engine room air intakes on Arctic ships.	----					60
e) Development of design requirements for Arctic ship propellers.	----	----	----			100
f) Investigate the over-thrust on the propulsion system due to ice loads on the propeller.		----				60
g) Investigate the benefits of protection of the propeller from ice loads.		----	----			200
h) Investigation of the effect of ice on shafting and sterntube bearings.		----	----			100
i) Investigate the problems of prime mover displacement due to thrust bearing deflection under ice loads.			----	----		75
j) Develop methods to protect gearing from overtorques.		----	----			60
k) Investigate the limitations in the use of various shaft seals.			----			50
l) Field tests to measure the reduction gear loading due to ice loads on the propeller.	----	----	----	----	----	250
m) Identify the parameters which should be specified for Arctic ship gears.				----		50
					TOTAL	1,205

Icing of intakes to the engine room and engine has potentially serious consequences. It may cause engine damage, cause the engine to stall and endanger the ship, cause blow back from boilers and even cause a sufficient pressure loss in the engine room to result in damage to bulkheads.

Approximate Cost - $60,000
Priority - High

d) Perhaps the most important parameter to be determined when designing a propulsion system for Arctic class ships is the loads on the propeller and shafting system brought about by ship ice interaction. There is very little knowledge of the actual loads. The guidance provided by the CASPPR and classification societies rules is not based upon present day evidence and knowledge.

The design loads for the propellers of Arctic ships should be studied and be based on both full scale measurements from existing ships and modern theory. Ice loads related to ice class, ship length and draft and propeller type and protection should be determined to provide the designer with more reliable guidance and to update the present regulatory approach.

Approximate Cost - $100,000
Priority - High

e) Shafting load can be increased due to the effect of ice entrained in the propeller. The additional load will be additive to normal shafting and sterntube bearing loads and may prove to be significant. At present there is no requirement by the rules to consider added mass due to ice (although in rational alignment calculation added mass due to water is allowed) and there is no requirement to consider the affect of propeller ice loads on shaft line bearing loads, the assumption being that a sterntube bearing length (for an oil lubricated white metal lined bearing) of 1.5 D will automatically provide a sufficiently large bearing area.

The effects of ice entrained in the propeller should be investigated for the influence on shafting stresses and on sterntube bearing loads. The investigation should also confirm that under conditions of ice loading the present rule requirements for stern tube bearing length are adequate.

Approximate Cost - $100,000
Priority - High/Medium

f) There is an ongoing problem of means to isolate the engine from the propeller thrust loads. While this problem is not severe for the present size of ships, as the thrusts presently used are moderate and can be absorbed by the structure without significant axial deflection, for large ships with high thrusts this will not be the case. Two approaches can be taken; either the structure can be made massive to increase stiffness and minimise the axial movement under thrust, or an axially compliant coupling can be developed which will permit axial movements under full torque loading. At present the only coupling which has this potential is the diaphragm type coupling which does not have the torque carrying capacity to make it suitable for very large ships.

The problems of the transmission of axial displacements to the primemover due to thrust bearing deflection should be studied to determine the true extent of this problem and solutions developed.

Approximate Cost - $75,000
Priority - High/Medium

g) The interface between the ships propulsion system and ice loads is via the propeller. Therefore, if ice ingestion by the propeller can be minimised, the design ice load requirement of the propulsion system can be reduced. At present there are no regulatory allowances to reduce the size of the propeller components to take into account the possible benefits of devices which may protect the propeller from ice loads.

This potential improvement in the operating requirements for propellers on icebreaking ships should be investigated.

Approximate Cost - $200,000
Priority - Medium

h) Propeller shafting external seals are essential for oil lubricated bearings, and the continued efficiency of the shaft sealing system is wholly dependent upon shafting rubbing speed, shaft surface finish, shafting roundness, shafting stability and lack of axial movement of the shafting in the seal. The result of a seal failure in the Arctic of a ship fitted with a white metal lined sterntube bush will be immobilisation of the ship. The efficiency of this type of seal quickly diminishes as shafting diameter increases.

The limitations of the use of shaft seals, both lip and face type, should be investigated with a view to inclusion in the regulations governing the use of seals.

Approximate Cost - $50,000
Priority - Medium

i) In the present rules there are regulations specifying the machinery system in terms of ice torques but no regulations which specify the ice thrusts to be used. The probable over-thrusts for ice class ships should be calculated with a view to inclusion in the Regulations.

Approximate Cost - $60,000
Priority - Medium

j) Although the present CASPPR requires that the gearing of Arctic ships be specially protected from over-torques, this regulation is not applied as there are no known methods to carry out the intent of the regulations. However, the intent to protect the gearing from overtorques should be pursued and practical methods by which this can be achieved should be identified in order that the intent of the present CASPPR can be implemented.

Approximate Cost - $60,000
Priority - Medium

k) It is recommended that the parameters essential to the specification of a reliable gear design be documented in order that the limits, if any, which presently exist to increasing gear size and capacity above present practice, can be understood. Those parameters which are specially applicable to gears in Arctic ship service should be highlighted in order that they may be addressed, if appropriate, in regulations.

Approximate Cost - $50,000
Priority - Low

7.3.4.4 General Outfit and Auxiliary System

The deficiencies in relation to general outfit and auxiliary systems cover a wide range of equipment and systems. Of most importance is the effect of ice on the requirements of steering gears. This is a subject of great concern to ship safety and should be given a high priority. Other areas of interest relate more to improvements in the practicality of the ship design from the operations viewpoint. To more grpahically illustrate the proposed programme, the projects are listed in Figure 7.3.6 with an indication of the timeframe for completion and cost.

a) The deck machinery presently being used on Arctic ships has generally performed well. Experience has been gained with all of the major system types and, while there are specific benefits associated with each option, all appear to be technically acceptable. Special care must be taken with the choice of materials, hydraulic oil and lubricants, and with the protection of equipment against mechanical damage. Investigation is required in the following areas:

- the protection of deck equipment from icing and the design of de-icing systems.

- the design of enclosed mooring flats where the working environment can be controlled, and the design of equipment shelters for the open deck.

- the extent to which low temperature materials are necessary in deck equipment.

Approximate Cost - $200,000
Priority - Medium

FIGURE 7.3.6

PROPOSED GENERAL OUTFIT AND AUXILIARY SYSTEM RESEARCH

PROPOSED RESEARCH	YEARS					TOTAL COST (000,s)
	1	2	3	4	5	
a) Develop means for the protection of deck machinery on Arctic ships.		-----	-----			200
b) Field tests to measure mooring forces and assess material suitability.			-----	-----		200
c) Steering gear research:	----					50
i) Means to protect the rudder from ice loads.	-----	-----				150
ii) Field tests to measure the magnitude and influence of ice loads throughout the steering system.	-----	-----				500
iii) Develop steering gear design requirements.		-----	-----			100
d) Field tests to aid in the development of de-icing and anti-icing features.	-----	-----				250
e) Hull coating research:						
i) Field tests to measure the operating conditions for low friction coatings.	-----	-----				200
ii) Investigation of the hull areas where the ice impacts and abrasion occurs.			-----	-----		75
f) Investigation of how noise and vibration can be reduced in accommodation spaces.				-----	-----	50
					TOTAL	1,775

b) The mooring systems presently used on Arctic ships are similar to those on non-Arctic ships, and appear to have performed satisfactorily. However, consideration is now being given to enclosed mooring flats, strain gauging the mooring lines to measure forces acting on the ship, and using polyester as a material for the mooring lines. The deficiencies in our knowledge of mooring systems relate mainly to the forces acting on the ship when moored in a variety of situations. This aspect of Arctic ship operation should be the subject a full scale measurement programme based on existing ships.

   Approximate Cost - $200,000
   Priority - Medium

c) The design requirements for steering systems depend on the main dimensions and mission of the ship being considered. Ships which are long and deep are less likely to expose the rudder to severe ice interaction than short and shallow draft ships which may be used for aggressive ice management duties. The design requirements which are enforced by the regulatory authorities are minimum standards.

   It must be recognised that Canada presently has no year-round operating capability in the Arctic and that future ships may be faced with onerous operating conditions. Present practice may prove to be inadequate for High Arctic ships which must manoeuvre in multi-year ice. Only a greater understanding of the rudder/ice loads, and of how these loads are absorbed by the steering gear system, will give confidence that the present design requirements are still acceptable. Specific research projects which should be iniated are:

   i) The protection of the rudder from ice loads by innovative stern design without detracting from the ship's hydrodynamic or icebreaking performance.

      Approximate Cost - $150,000
      Priority - High

   ii) Field tests to investigate the magnitude and effect of rudder/ice interaction on each element of the steering system include "backing-up" operation in ice.

      Approximate Cost - $500,000
      Priority - High

   iii) The way in which the steering system should be designed to accommodate the actual loads.

      Approximate Cost - $100,000
      Priority - High

d) Our present knowledge of probable icing conditions in the Arctic is very limited. Little attention has been given to the problems caused by the icing of deck equipment or of safety and evacuation systems. Anti-icing and de-icing systems must be developed to ensure personnel safety and to increase ship efficiency. Experiments should be designed and carried out to aid in developing anti-icing or de-icing systems which are practical for Arctic ships.

Approximate Cost - $250,000
Priority - High/Medium

e) The choice of coatings, for ships which operate in the Arctic, depends on the mission of each ship. For topside areas, chlorinated rubber paint is commonly used due to its cold temperature properties. However, this paint is also used on non-Arctic ships. Below the waterline, the problems of hull abrasion and the search for a low friction coating have resulted in many research programmes. The outcome of these programmes is; a better understanding of the nature of hull/ice interaction and, coatings which appear to satisfy both requirements. Inerta 160 and Zebron, particularly Inerta 160, are now commonly used on icebreaking ships. The deficiencies in our present knowledge of hull coatings and their application may be summarised as:

i) Investigation of thehull areas where most of the ice impacts and abrasion occurs.

Approximate Cost - $75,000
Priority - Medium

ii) Field tests to measure the true hull/ice friction factors, and the operating conditions of the coating, in terms of load versus time and frequency.

Approximate Cost - $200,000
Priority - High

f) The accommodation facilities required on Arctic ships are in many ways similar to those on non-Arctic ships, although the severe climate of the Arctic does impose design requirements in regard to air temperature. These requirements will be reflected in such areas as; insulation, climate systems, and vibration control measures. The most important deficiency in our present knowledge is how noise and vibration can be reduced effectively to acceptable levels.

Approximate Cost - $50,000
Priority - Medium

8. CONCLUSIONS

This report has resulted from an extensive review of Arctic Ship Technology. The work has covered the full range of; environment, ship operations and ship design. The state-of-the-art in each area has been identified as have the information deficiencies. A research programme has been proposed to address these deficiencies, having regard for the most likely future Arctic Shipping Scenarios.

To ensure that the work has been thorough, the project team was comprised of environmental scientists, ship operators and ship designers with an up to date understanding of Arctic Ship Technology. The principal objective was to produce a reference manual for designers, operators, regulators and researchers. The report is well structured and supported by extensive references to published literature, with special data sheets for the most important publications.

The proposed research programme is subdivided into the main sections of the report and detailed discussion is provided of each item along with an indication of cost, timeframe and priority. The programme spans five years with total proposed expenditures as follows:

Research Area	Cost 000's
Environment	2,950
Ship Operations	
- safety	1,050
- navigation	1,850
- communications	575
Ship Design	
- hull structure	2,850
- hull design and performance	2,350
- propulsion	1,205
- general outfit and auxiliary systems	1,775
	14,605

When compared to the cost of designing and constructing several Arctic resource etraction projects this level of research expenditure is a small fraction of one percent. The overall cost is low but the importance is high and the economic benefits can be demonstrated to be substantial.

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ARCTIC SHIP TECHNOLOGY
(The State Of The Art - 1986)

~~Volume II~~
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Prepared for

Transportation Development Centre
Montreal, Quebec

By

Melville Shipping Ltd.
Ottawa, Ontario

In Association With

Arctec Canada Limited
Canarctic Shipping Company Limited

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Un rapport sommaire de ce document est également disponible en français:
"Technologie des navires de cote arctique" TP 8387F

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1. INTRODUCTION

This volume comprises the bibliography and literature data sheets for the background material which was identified as relevant to Arctic Ship Technology. The bibliography contains a list of all identified literature, whereas the data sheets are provided only for those items of literature which have been referenced in the main text which may be of particular interest.

The bibliography is arranged by section (e.g. Ship Operations or Propulsion) and alphabetically, as are the data sheets. To find a particular item, either in the bibliography or data sheets, search through the authors names alphabetically using all letters in the primary authors name. Those references for which data sheets have been prepared are identified with an asterisk (*).

Every attempt has been made to include all important literature in the bibliography. Similarly, when preparing the main text, it is the most important literature which has been referenced. While the bibliography and data sheets attempt to fully cover the subject matter, there may be deficiencies. Hopefully those deficiencies will not detract from the presentation of the state-of-the-art, or from the conclusions and recommended research programme.

2. BIBLIOGRAPHY AND DATA SHEETS

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REFERENCE: Arctec, 1983.

TITLE: Hazardous ice atlas of Arctic Canada.

AUTHOR: Daley, C.; Edworthy, J.

SOURCE: Transport Canada.

ABSTRACT:

An atlas of hazardous ice conditions for shipping in the Canadian Arctic has been prepared for Transport Canada, Canadian Coast Guard (Northern). The conditions presented represent monthly estimates of typical conditions for pressure ridges, multi-year ice and glacial ice throughout the Arctic. The estimates are based substantially on observed data where available, and on consensus projections to 'fill the gap'. The atlas is meant to be used to assess the general potential risk to Arctic shipping, not as data for navigation or other purposes.

When this document was prepared it was unique in presenting a wide range of data together in one format. It also included the most up-to-date sources at that time. The sea ice data have been superseded by more recent work but the iceberg populations are still the most consistent database covering the whole of the eastern arctic.

REFERENCE: Arctec, 1985.

TITLE: Studies in connection with updating the Arctic Shipping Pollution Prevention Regulations, Group IV.

AUTHOR: Daley, C.; Perchanok, M.; Harwood, M.

SOURCE: Transport Canada (TP6274E).

ABSTRACT:

The Arctic Shipping Probability Evaluation Network (ASPEN) is a computer model developed by the Canadian Coast Guard to assist in evaluating and developing regulations for arctic shipping. This study comprises specific enhancements to the ASPEN system. The ice and visibility data has been updated. Improved algorithms have been developed, specifically in the areas of hazard detection, first year ice load and limiting ice loads due to bending failure. The computational structure of the program has been revised to permit hundreds of sequential runs of the program. In an attempt to establish a basis of comparison for ASPEN results a review of marine and other industry damages was conducted. This involved an update of ice damage to ships in the Arctic and a survey of both marine and non-marine damage incidents. Finally a plan was constructed for future ASPEN developments.

The study includes a review of environmental data in the Canadian arctic for purposes of improving the database used in Coast Guard's ASPEN model. Parameters reviewed include first year ice thickness, old ice concentration, ice ridge frequency and geometry, old ice floe size and at-sea visibility.

First year ice thickness was improved using measurements by A.E.S. up to 1982 and an original contour map of mean thicknesses prepared as part of this study.

Old ice concentration data were based mainly on the 1981 A.E.S. atlas and supplement of 1984 with additional data for the Lancaster Sound and Parry Islands regions. Concentration values extracted were the most severe of the median values for each month and therefore provide a relatively severe estimate of ice conditions. An additional concentration class was added to describe a presence of ice where the median concentration is less than 1 tenth and wasobserved in more than 1 but less than 51 percent of years observed.

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Published and some proprietary data on ice ridging and floe sizes were reviewed, including measurements from A.E.S. and private airborne surveys plus surface measurements, and the most representative of these were presented for incorporation in the database.

Causes of reduced visibility at sea were reviewed and possible data sources for Canadian arctic marine areas were compared. A database of reduced visibility frequencies was constructed from raw MAST and LAST data on file at A.E.S.

The study provides the best monthly estimates of the above parameters in the Arctic Shipping Control Zones available as of March 1985.

REFERENCE: A.E.S., 1982a.

TITLE: Canadian climate normals.

AUTHOR: Canadian Climate Centre

SOURCE: Atmospheric Environment Services, Environment Canada, 1982.

ABSTRACT:

Data was collected from land station data based on the period 1951-80 and are presented in separate volumes to describe the radiation, temperature, precipitation, degree-days, wind and frost in Canada.

This is the standard climatological data set used in Canada and conforms to the 30-year normal period recommended by the World Meteorological Organization.

REFERENCE: A.E.S., 1982b.

TITLE: Updated ice thickness climatology for Canadian stations.

AUTHOR: Ice Climatology and Applications Division

SOURCE: Atmospheric Environment Service (AES), Environment Canada, manuscript, 1982.

ABSTRACT:

Weekly ice thickness measurements are tabulated for 61 coastal weather stations in Canada. Weekly tabulations include mean ice thickness and its standard deviation, maximum and minimum thickness, number of ice thickness observations, mean, standard deviation and number of observations of snow depth.

This is the most consistent source of long-term data for first year ice thickness in Canada. A limitation of the data is that it is from near shore sites only and may not be representative of offshore ice thickness and snow depth.

REFERENCE: Brower, 1977.

TITLE: Climatic atlas of the outer continental shelf
waters and coastal regions of Alaska.

AUTHOR: Brower, W.A., et al

SOURCE: Arctic Environmental Information and Data Centre
(AEIDC), University of Alaska, 1977.

ABSTRACT:

This projects attempts to establish the present knowledge of climatological conditions in three Alaskan marine and near coastal areas that are important to resource development of the outer continental shelf - The Gulf of Alaska (Vol. I), the Bering Sea (Vol. II), and the Chukchi and Beaufort Seas (Vol. III).

The maps, graphs, and tables in the atlas present a detailed climatic profile of the marine and coastal regions of Alaska. Statistics detail means, extremes, and percent frequency of occurrence of threshold values for these elements: wind, visibility, present weather, sea level pressure, temperature, clouds, and waves and such supplemental information as storm surges, tides, sea ice, surface currents, bathymetry, detailed weather, and aviation weather. Data came from 600,000 surface marine observations and 2 million observations for 49 coastal land stations and provide the best possible climatological picture of the outer continental shelf waters and coastal regions of Alaska.

The maps and text provide a good overview of the climate and meteorological conditions in Alaskan waters. The major limitation is that precipitation amounts are given only on an annual basis, and snow accumulation is not reported.

REFERENCE: Burns, 1974.

TITLE: The climate of the Mackenzie Valley - Beaufort Sea.

AUTHOR: Burns, B.M.

SOURCE: Atmospheric Environment Services (AES),
Environment Canada, 1974.

ABSTRACT:

The study presents a broad overview of climatic factors pertinent to the Mackenzie Valley-Beaufort Sea. Emphasis is on probability estimates of extremes of precipitation, temperature and winds, as well as duration of critical weather types. Energy exchange, snow cover, wind-chill, inversion frequencies and elements which individually or in combination are important in the resolution of heat flow and environmental quality problems were treated as completely as data permitted.

This report is similar in scope to the one by Maxwell, but covers a more restricted area. Its emphasis is on climatology of the Mackenzie River valley and very few marine observations are included.

REFERENCE: C-CORE, 1985.

TITLE: Canadian sea ice information system (CSIIS).

AUTHOR: Centre for Cold Oceans Engineering (C-CORE), Memorial University, St. John's, Nfld.

SOURCE: Canadian sea information system user manual, September 1985, plus on-line searches at Arctec Canada Limited.

ABSTRACT:

Quantitative and qualitative information on sea-ice, glacial ice and artificially thickened ice in the Canadian Arctic are assembled on an on-line data base. The information describes climatological values of ice type, morphology, movement concentration, physical and mechanical properties which are of interest to offshore operators and regulators.

Data relating to ice type and concentration are derived from the climatological data base used for the A.E.S. arctic ice atlas and are presented in summarized format as mean values or frequency distributions for a user-defined region or site and date range.

Data relating to ice morphology and physical/mechanical properties are derived from non-confidential government and industry reports and papers. They are presented in text format and include raw data where available. Reports can be accessed by geographical region, data, author or subject. Data can be assessed on-line through a menu driven program.

VDIID is a very useful data source for researchers who do not have access to an extensive in-house library of information on ice properties or to the A.E.S. climatological ice data base. It can be accessed on-line from remote terminals and presents a wide variety of data in high quality, graphical or tabular format.

The main limitation to CSIIS is the rate at which data can be retrieved for large areas. The interactive response is relatively slow, and geographical access to A.E.S. climatological data is limited to 5^{o} latitude by 15^{o} longitude during any one interactive session. Thus, a map showing variations in a particular property over the Canadian Arctic cannot be produced.

REFERENCE: FMS Engineers, 1983.

TITLE: Evaluation of 1982 ice conditions using March SLAR and July photograhic surveys of Wellington, Queen's Channels and McDougall Sound.

AUTHOR: Embacher, U.

SOURCE: Canarctic Shipping Company Limited.

ABSTRACT:

This report presents the results of a twin otter overflight of Wellington Channel, Queen's Channel and McDougall Sound on July 2, 1982, to verify ice conditions recorded on SLAR obtained earlier in March.

A limited number of small multi-year floes were identified in the otherwise smooth first year ice of Wellington Channel. Multi-year ice concentrations were found to be much higher north of Cornwallis and Little Cornwallis Island with floe sizes increasing significantly toward the Bathurst Island coastline. Northern McDougall Sound was found to be mostly smooth first year ice with only a trace of multi-year ice. However, southern McDougall Sound at the entrance to Barrow Strait was found to be heavily rubbled and ridged. A dividing line was noted between these two regimes occurring with north wester-south-west running leads between Baker Island, Cornwallis Island and Griffith Island. It was speculated that these leads may re-occur every year and that a vessel attempting an early July entry to LCI may be able to utilize these leads to avoid the difficult ice of this area.

This report presents a good overview of the types of conditions that can be expected in the study area at that time of the year.

REFERENCE: Hotzel, 1983.

TITLE: Icebergs: their physical dimensions and the presentation and application of measured data.

AUTHOR: Hotzel, I.S.; Miller J.D.

SOURCE: Annals of Glaciology (4), 1983.

ABSTRACT:

A knowledge of the dimensional characteristics of icebergs off the east coast of Canada is required for both scientific and engineering purposes. To fulfill this need, hydrocarbon exploration in the region has been supported by a program aimed at collecting morphometric data on icebergs. In addition to providing operational support for activities such as iceberg towing, this program has yielded information which will be useful for the engineering design of offshore structures. Functional relationships between the dimensions of icebergs are presented and ratios between the linear dimensions are examined. These ratios are used to calculate preliminary values for draft and mass on the Grand Banks and are demonstrated to give reasonable values for draft of icebergs off Greenland.

The data was collected from surface and airborne measurements, and provide a relatively large and accurate database on iceberg dimensions. The data collection area was off the Labrador coast from 52° to 60° N latitude. Labrador Sea data are compared with measurements from the Grand Banks but applicability or extension of the data to northern areas is not discussed.

REFERENCE: Intera, 1985.

TITLE: Lancaster Sound winter ice regime study.

AUTHOR: Atcheson, C.

SOURCE: Canarctic Shipping Company Limited.

ABSTRACT:

This report documents a study of the ice regime of the Lancaster Sound region between November 1984 to March 1985, using high resolution STAR-1 SAR and SLAR imagery. The objectives of this study were to gain a better understanding of the spatial and temporal changes in the ice cover with regard to concentration, percentages of old ice, glacial ice, and the frequency distribution of small floes of old ice.

Results from the anlaysis of the high resolution STAR-1 SAR indicated that a very high concentration of old ice occurred throughout eastern Lancaster Sound in the first week of November. However, from early November onward, the old ice moved easterly out of Lancaster Sound into Baffin Bay. The percentage of old ice in the Sound diminished during the winter and by mid-January there was very little old ice left in the Sound. Glacial ice fragments were primarily interpreted in the landfast ice in Lancaster Sound with very few in the moving pack ice.

The movement of old ice south from Nares Strait had stopped by mid-December until mid-March. A very high concentration of old ice in small floe sizes were identified from the SAR imagery during the early November period.

This report represents the first analysis of the winter ice regime of Lancaster Sound using a high quality data set such as the STAR-1 SAR. The findings of this study indicated that for the winter of 1984-85, favourable conditions for navigation existed in the mid-December to mid-January period. This report is the first in a series of annual ice regime studies to be undertaken of Lancaster Sound. Such a detailed data base will greatly aid the understanding of this regime for extended season navigation.

REFERENCE: LaBelle, 1983.

TITLE: Alaska marine ice atlas.

AUTHOR: LaBelle, J.C., et al

SOURCE: Arctic Environmental Information and Data Centre (AEIDC),
University of Alaska, 1983.

ABSTRACT:

Monthly data are assembled to describe the main characteristics of sea ice growth, drift and deformation and iceberg drift in the Beaufort, Chukchi and Bering Seas and the Gulf of Alaska. Climatic factors related to ice growth and drift are also presented.

This atlas presents a first cut at a unified compilation of ice data for Alaska. The raw data were not as uniform as those used in Markham's atlas for Canadian arctic waters, and the accuracy and consistency of the monthly maps is not high.

REFERENCE: Levine, 1974.

TITLE: Advances in the development of commercial ice-transiting ships.

AUTHOR: Levine, G., Voelker, R., Mentz, P.

SOURCE: SNAME Annual Meeting, Paper No. 8, November 1974.

ABSTRACT:

The results of three years of model tests, full scale experiments, and technical design studies conducted in response to a national need for the development of commercial ice-transiting marine transportation systems are presented. This need is briefly documented in terms of the required transport of Great Lakes coal and arctic crude oil to the year 2000. The technical focus of the paper is directed toward ice impact loads on the hull of commercial ships and methods to reduce the resistance of bulk carriers in ice. Ice impact loads were recorded for two years aboard the ore carrier LEON FRASER operating between Lake Superior and Lake Michigan. The techniques of dimensional analysis were applied to these data to develop predictor equations which give ice forces as a function of ship form, speed, ice thickness, and ice strength. A series of icebreaking model tests was also performed on Great Lakes ore carriers and a predictor equation was developed which incorporates length, beam and stem angle variation. Results of experiments directed toward the reduction of ship resistance in ice fields are also presented. The three phase program included: model tests of various concepts to reduce ship resistance in broken ice-clogged channels, design and development of an air coating system, and full-scale testing of this system as installed in the LEON FRASER. Scenarios describing technical events leading to year-round commercial ship operations in the Great Lakes and Arctic regions are presented as well.

This paper offers a comprehensive review of model and full scale testing programs, methods of resistance reduction and future requirements.

REFERENCE: Markham, 1981

TITLE: Ice Atlas, Canadian Arctic Waterways.

AUTHOR: Markham, W.

SOURCE: Atmospheric Environment Service (AES), Environment Canada, 1981 and Supplement 1984.

ABSTRACT:

Maps showing median, maximum and minimum concentrations of all ice and of old ice as well as frequency of occurrence of old ice, are presented for the Eastern, Far Northern and Western sections of the Canadian Arctic. Median, maximum and minimum conditions are presented for the period May 21 to October 29, while one map per month shows generalized ice conditions for the winter months. The maps are based on 20 years' weekly observational data which were digitized at 958 grid points.

This Atlas is a standard reference for North American ice climatologists. The data set from which it is derived is the most comprehensive data available on the sea ice cover in Arctic Canada and probably Alaska. The atlas itself is the most comprehensive document on ice cover at the scale presented and over the historical period presented.

The atlas has been criticized for perceived inaccuracies and inconsistencies related to the original data base of airborne and ship ice observations and this is possibly the case. Over the historical period however, the inaccuracies are unlikely to effect the use of the data except where extreme values are concerned.

Another drawback is in the Atlas resolution. Since it is based on an approximately 30 mile grid, use of the atlas boundaries to describe local conditions for instance at an anchorage, can be misleading.

A drawback to the atlas approach is that median and extreme are presented for each grid point independent of surrounding points. This presents an overall composite image of the ice cover which is probably not realistic. For instance, maximum map shows the maximum concentration at every grid point on a particular date, whereas it is most unlikely that the maximum occurs at all grid points simultaneously.

REFERENCE: Maxwell, 1980.

TITLE: The climate of the Canadian Arctic islands and adjacent waters.

AUTHOR: Maxwell, J.

SOURCE: Atmospheric Environment Services (AES), Environment Canada, 1980.

ABSTRACT:

This study presents a broad overview of the climatic factors pertinent to the Canadian Arctic Islands and their adjacent waters. The emphasis is on probability estimates of temperature, wind, and precipitation, as well as the duration of critical weather types. The subjects of energy exchange, wind chill, blizzards, sea state and sea ice, temperature inversion frequencies, and typical synoptic patterns are treated as completely as time and data permitted. A subdivision of the study area into climatic regions is presented in the final chapter.

This is the most complete climatological description of the Canadian Arctic islands. It encompasses all important aspects of climate and includes an abundance of maps and tables which illustrate the spatial and temporal patterns and variations in all of the important parameters. It includes both original analyses of climatological data and material from other sources.

The main weakness in the study is that some of the data presented are dated and based on a short period of record. The A.E.S. MAST and LAST databases provide more up-to-date and long-term statistics for many of the variables covered.

REFERENCE: Meserve, 1974.

TITLE: U.S. Navy Marine Climatic Atlas of the World, Vol. I, North Atlantic Ocean.

AUTHOR: Meserve, J.M.

SOURCE: U.S. Naval Weather Service Detachment, Asheville, 1974.

ABSTRACT:

Data derived from TDF-11 are summarized in an atlas of marine and atmospheric climatology of the North Atlantic Ocean, from the equator to 70° N latitude.

This atlas provides a complete summary of marine climate in the North Atlantic, but most parameters presented for Davis Strait and especially Baffin Bay are based on a very limited number of observations.

REFERENCE: Mofjeld, 1984.

TITLE: Recent observations of tides and tidal currents from the Northeastern Bering Sea Shelf.

AUTHOR: Mofjeld, H.

SOURCE: Pacific Marine Environmental Laboratory, NOAA Technical Memorandum ERL PMEL-57,Seattle, 1984.

ABSTRACT:

Tide and tidal current observations from the Northeastern Bering Sea Shelf and a comparison of these observations with theory and numerical models are reported in this memorandum.

Pressure observations at seven stations show that the diurnal tides dominate the outer shelf. The diurnal amplitudes decrease exponentially inshore from the shelfbreak at a rate consistent with subinertial Sverdrup waves. The phase lags of the diurnal tides vary little over the shelf. The semidiurnal amplitudes change considerably between stations; on the outer shelf there is some influence of a semidiurnal amphidromic system off Cape Navarin. The phase lags of the semidiurnal tides are earliest at the shelfbreak and increase toward the east and north. The tides become progressively smaller and semidiurnal toward the north and east from the shelfbreak. Non-tidal pressure fluctuations become stronger in the same direction, dominating the pressure signal on the Northern Bering Sea Shelf. There are some seasonal variations in the observed tide and tidal current with slightly larger diurnal tidal amplitudes and smaller semidiurnal amplitudes during late winter at some stations. Numerical models reproduce the general features of the observed tides and tidal currents.

REFERENCE: Norland, 1984b.

TITLE: Study and recommendations regarding opening and closing dates for entry of the M.V. ARCTIC into CCG ASPPR Zones 6 and 13.

AUTHOR: Lapp, D.

SOURCE: Canarctic Shipping Company Limited.

ABSTRACT:

This paper compares the opening and closing dates of the ASPPR Zones 6 and 13 to the known historical record of the ice regimes leading to the Nanisivik (Zone 13) and Polaris (Zone 6) mine sites. A variety of data spanning the years 1960 to 1983 were used for this study.

The break-up sequence of both McDougall Sound and Admiralty Inlet are presented. It was found that the ice regimes for the shipping routes to Polaris and Nanisivik are remarkably similar in typical to better than average years. For both destinations the channels are composed almost entirely of first year ice with only a small amount of old ice entering during the open water period. The limited strength and thickness data are similar between McDougall Sound and Admiralty Inlet.

The conclusion of the study is that the opening and closing date to the Polaris mine site (in Zone 6) are too severe and do not properly represent the ice regime or the capabilities of the M.V. ARCTIC. The proposed opening dates for the M.V. ARCTIC under her Class 2 configuration for Zone 13 is June 15 to November 30 and under her upgraded Class 4 configuration it is June 1 to December 15. For Zone 6 the recommended updates are July 15 to November 22 as a Class 2 and July 1 to November 30 as a Class 4.

This report presents an interesting comparison between the ice regime of Admiralty Inlet and McDougall Sound. The similarities between the two regimes are quite striking. However, the recommendations as to the closing dates for Zone 6 and 13 appear somewhat conservative. Recent experience by Canarctic indicates that early winter voyages by the upgraded M.V. ARCTIC may actually be easier than late fall voyages. In addition, the possibility of much higher incidents of ridging and rubble across southern McDougall Sound at the entrance to Resolute passage may pose a problem for an early season entry of the M.V. ARCTIC to LCI not mentioned in this report. Clearly, more work on the ice regimes of these two areas as it relates to the actual performance of the upgraded M.V. ARCTIC is required before further assessments of the ASPPR regulations are attempted.

REFERENCE: Norland, 1985a.

TITLE: Test ice for dedicated test M.V. ARCTIC 1984, location, monitoring, verification and specific data - Phase I.

AUTHOR: Lapp, D., Hagen, D., Wells, D.

SOURCE: Canarctic Shipping Company Limited.

ABSTRACT:

This report is the first in a series dealing with ice property measurements collected for the full scale testing of the M.V. ARCTIC undertaken in June 1984. This report is an initial survey of poential sites where suitable thick multi-year ice could be found. From an initial review of AES ice charts and ice reconnaisance information, three potential areas were investigated in detail. These were:

1. Coburg Island to Nares Strait,
2. Norwegian Bay, and
3. Byam Martin Channel.

The area around Coburg Island was found to contain a large shorefast area with numerous imbedded old ice floes. These floes were documented to have frozen into place the previous fall and were of a suitable dimension for testing. In addition, the location of the test site was found to be favourable for logistical reasons.

Numerous suitable old ice floes in large sizes were located in the Byam Martin Channel region. However, the late August access time period was found not to be advantageous due to logistical reasons and the likely advanced state of decay of the ice. Similar conditions of suitable old ice but unsuitable logistics and timing were identified for the Norwegian Bay location. It was therefore recommended that the Coburg Island site be considered for the full scale testing.

Although the sequence of reports in this series deal with finding suitable old ice for the June 1984 dedicated testing, the review of old ice properties and distribution presented in this report is very useful to anyone looking for information on old ice.

REFERENCE: Norland, 1985b.

TITLE: Bent Horn Demonstration Project - Task 1: initial verification of 1985 ice conditions for strategic route planning.

AUTHOR: Wells, D., Lapp, D.

SOURCE: Canarctic Shipping Company Limited.

ABSTRACT:

This report documents the results of a field survey to collect ice property measurements in the Byam Martin Channel and Erskine Inlet areas between May 28 and June 4, 1985. Ice thickness and surface feature measurements were collected along the potential shipping routes to Bent Horn. STAR-1 SAR imagery, collected the previous fall, was ground truthed during this exercise.

First year ice thickness measurements averaged 200 cm in the southern section of the study area and 237 cm to the north. The first year ice of Arnott and Boyer Straits and Pell Inlet were found to be thinner, averaging 180 cm, than the other areas in the study region. The second year ice of Erskine Inlet was found to average 210 cm with the central portion of the Inlet being 10 percent thicker than the northern or southern sections. This was found to be consistent with the historical break-up pattern of Erskine Inlet where the central portion remains longer than the other areas of the Inlet.

The old ice frozen into Byam Martin Channel were found to be conglomerate floes (i.e. comprised of ice of variable ages). This ice was found to have thicknesses ranging from 250 to 350 cm with the occasional thickness exceeding 565 cm. The STAR-1 SAR was found to provide excellent detail on the ice regime and allowed for accurate placement of the ice survey stations on the imagery. It was recommended, based on these survey results, that the optimum route for the M.V. ARCTIC to Bent Horn was via Pell and Erskine Inlet and eastern Arnott Strait.

This report gives good ice thickness and surface feature data for this region for the time period of the study. It also confirms the value of START-1 SAR imagery in guiding field parties undertaking ice property investigations.

REFERENCE: Parker, 1983.

TITLE: Weather, ice and sea conditions relative to marine Arctic transportation.

AUTHOR: Parker, N., Alexander, J.

SOURCE: Canadian Technical Report of Hydrography and Ocean Sciences, No. 26, Atmospheric Environment Service (AES), Environment Canada, 1983.

ABSTRACT:

This study presents an overview of climatic factors pertinent to marine transportation through the Northwest Passage. The subjects of wind, visibility, temperature, ice and sea state in an arctic environment are treated as completely as time permitted. The final section places special emphasis on these climatic factors along the Northwest Passage from Bering Strait to southern Davis Strait.

This document is compiled mainly from other sources.

REFERENCE: Polar Research and Engineering, 1983.

TITLE: Ice trafficability in northern Baffin Bay - June 1 to July 15.

AUTHOR: Lapp, D.

SOURCE: Canarctic Shipping Company Limited.

ABSTRACT:

This report is an ice regime study of Baffin Bay for the period of June 1 to July 15. The primary data source used in the analysis was NOAA visual and near IR images as well as some Landsat, SLAR and AES ice chart information spanning the period 1972-81. The purpose of the study was to see if the presence of Baffin Bay leads, first identified during APP ship routing studies, were in existance and applicable to navigation for a lower ice class vessel such as the M.V. ARCTIC during the June and July period.

Between June 1 and July 15, the major change in the Baffin Bay ice regime occurs from the joining of the North Water with the open water of Lancaster Sound to form the north-western Baffin Bay pack ice edge. The eastward progress of this boundary is the major indicator of the severity of the year for this time period. The eastern Baffin Bay ice edge remains essentially stationary throughout June and only in July in good ice years does it move west of 60°W. By early June the high ice concentration becomes a matrix of closely packed floes rather than an ice cover punctuated by leads. Ice conditions at the start of June do not appear to be necessarily indicative of the ice break-up and movement in subsequent weeks.

The major conclusion drawn from this report is that since there is a transition from an ice cover with leads to a floe matrix during the early spring period, routing decisions should be based on selective routing around floes rather than leads.

This report gives a good overview of the ice regime of Baffin Bay for the June and July period. An analysis of expected ships performance based on the prevailing ice regime is also present.

REFERENCE: Robson, 1982.

TITLE: Ice regime study - report on observations programme during 1982 season.

AUTHOR: Robson, M.

SOURCE: Canarctic Shipping Company Limited.

ABSTRACT:

This report presents the results of the first in a series of ice observation programmes undertaken by Canarctic on board the M.V. ARCTIC. Ice conditions and ship performance are presented for the 1982 shipping season in Davis Strait, Baffin Bay, Lancaster Sound, Admiralty Inlet, Barrow Strait and McDougall Sound between June 22 and November 18, 1982. This report presents the results in two major sections. The first section is a generalized narrative of each of the six voyages of the vessel into the High Arctic. The second section presents a detailed analysis of data collected on the first voyage as well as results from ice thickness and Borehole Jack measurements taken for the thick first year ice in Baffin Bay, Admiralty Inlet and McDougall Sound.

The conditions encountered in Davis Strait and Baffin Bay were found to be somewhat below average during 1982 with the vessel required to sail well north of 74°N by mid-August to avoid the lingering Baffiun Bay ice pack. High concentrations of icebergs were encountered in Davis Strait and Baffin Bay during 1982 with the highest areas occurring near Disko Bay, where over 50 per hour were identified from the vessel. Other high iceberg concentrations were encountered in Northern Baffin Bay near Melville Bay and along the east coast of Baffin Island between Cape Dyer and Cape Christian. Ice conditions in Lancaster Sound and Admiralty Inlet were found to be above average during the 1982 season. The M.V. ARCTIC encountered little difficulty during the first voyage transitting the consolidated thick first year ice of Admiralty Inlet in three days. The first commercial cargo lift was undertaken from the Cominco mine on Little Cornwallis Island the last week of July. The vessel encountered very good ice condition with only scattered patches of heavily decayed first year ice. The vessel entered ASPPR Zone 6 on July 29, two weeks earlier than the official entry date for the vessel of August 15.

Heavy old ice conditions were recorded from the vessel across the entrance to Lancaster Sound during mid-October on her fifth inbound voyage to the min sites. These conditions were recognized as more severe than normal and resulted in the failure of the vessel to penetrate the entrance to Lancaster during her sixth voyage in early November.

The value of the observed ice and environment conditions encountered by the M.V. ARCTIC during her season extending voyages will only increase with time. The data collected on iceberg distribution, visibility and sea ice conditions encountered by the vessel during the 1982 season has formed the basis for an every increasing data set collected during the ice observation programmes. This data base will contribute significantly to the understanding of the Arctic environment as it would impact Arctic ship technology development.

REFERENCE: Voelker, 1981.

TITLE: Evaluating commercial Arctic marine transportation with polar class icebreakers.

AUTHOR: Voelker, R., DeBord, F.

SOURCE: SNAME Star Symposium, Ottawa, 1981.

ABSTRACT:

Environmental and ship performance data were collected aboard POLAR Class Icebreakers in 1979 and 1980 as part of a multi-year program to make an operational assessment of the feasibility of a year-round transportation system serving northwestern Alaska. The POLAR Class successfully operated through the North Bering Sea, Bering Strait, and South Chukchi Sea during this time period. From an analysis of the governing ice conditions and the capability of the POLAR Class icebreakers, three commercial icebreaking ships (MV ARCTIC, SS MANHATTAN, and a proposed Arctic tanker) were also evaluated to determine their ability to successfully operate along potential marine routes in Western Alaska. This paper provides some of the data and results from the first two years of the multi-year program.

2.3 Ship Operations

SHIP OPERATIONS

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SOURCE: Transport Canada (TP6903E).

ABSTRACT:

A test of personnel survival on ice was conducted by Arctec on behalf of the Canadian Coast Guard from the USCGC POLAR SEA on April 1, 1985, in the Navarin Basin of the Bering Sea. This test examined the use of a US Coast Guard approved inflatable liferaft as a shelter on ice covered waters. Various means of transporting the raft over level ice and a rubble field were examined both for the raft contained in the storage canister and in the inflated condition. The adequacy of the food, water, and survival equipment supplied in the raft, and the ability of the raft to keep the survivors warm and protected from the elements were examined. In addition, various types of cold weather clothing, including the Arctic exposure suit, and the use of a Jacob's ladder for descending from the ship to the ice were examined as part of this test.

Although, this report has a very limited scope (survivors were on the ice for only a few hours) it is nevertheless the only known report of such a test and is therefore very relevant. It should form the basis for future tests.

REFERENCE: Benedict, 1979.

TITLE: A study of iceberg detection for marine navigation.

AUTHOR: Benedict, C.; Hall, J.

SOURCE: Transport Canada

ABSTRACT:

A study of a variety of sensors for shipbased detection of icebergs and other ice obstacles is reported. The formation, distribution and ablation of icebergs are discussed as well as relevant ice properties. The state of the art of a range of technologies including radar, sonar, infrared and low light television is included. Program requirements for evolving a shipbased detection system are developed for a multi-sensor detection system. This follows from the report conclusion that no single sensor has sufficient performance to cover all weather possibilities.

This study could almost be classed as required reading for non-technical persons who require information on ice sensing technology. A most useful report for those requiring background information.

REFERENCE: Canarctic, 1985.

TITLE: Shipboard ice navigation support system Phase II - final report.

AUTHOR: Canarctic Shipping Company Limited

SOURCE: Canarctic Shipping Company Limited.

ABSTRACT:

This report presents the Phase II results of the Shipboard Ice Navigation Support System (SINSS) under development by the Canarctic Shipping Company Limited. In 1981, Canarctic embarked on a program to extend the shipping season of the M.V. ARCTIC within the high Arctic. Initial research undertaken by Canarctic in 1981 and 1982 lead to the establishment of the SINSS program for the spring of 1983. Phase I, undertaken during the 1983 shipping season, considered the development of a conceptual design for SINSS. The objective of Phase II, undertaken during the 1984 shipping season, was to define the minimum acceptable standard of information required for SINSS.

This report describes Part II of the SINSS development. Very usefull to the understanding of the SINSS concept.

REFERENCE: Canarctic, 1986.

TITLE: Development of an ice navigation console - final report.

AUTHOR: Canarctic Shipping Company Limited

SOURCE: Transport Canada (TP7469E).

ABSTRACT:

This report has been prepared by Canarctic Shipping Company Limited to document the utility of a dedicated ice navigation console work area on the bridge of the M.V. ARCTIC. In preparation for significant conversion of the vessel to extend its operating season in the Canadian Arctic, the navigating bridge was expanded to increase the work area during the initial OBO conversion in Thunder Bay in early 1985. The original intent was only to increase the wheelhouse size without incurring any major modifications to the internal bridge infrastructure. Planning for the latter would occur over the 1985 season, and would be ready for implementation during the final conversion of the vessel in Port Weller in the spring of 1986.

This report is an important first step to developing an ice navigation console. It puts forth the rationale design, implementation and evaluates the concept. This console has been fitted to the M.V. ARCTIC and has undercome an initial operational evaluation.

REFERENCE: Canarctic, 1986.

TITLE: Shipboard ice navigation support system phase III - final report.

AUTHOR: Canarctic Shipping Company Limited

SOURCE: Transport Canada (TP6695).

ABSTRACT:

This report presents the Phase III results of the shipboard Ice Navigation Support System (SINSS) program under development by Canarctic Shipping Company Limited. The primary objective of Phase III was to improve and test hardware systems onboard the M.V. ARCTIC for the acquisition and display of information required for ice navigation.

One field trial voyage was undertaken during Phase III, to the Bent Horn oil field on Cameron Island, and SINSS made an important contribution to the success of this voyage. The VIEWFAX was tested and performed well during the field trials. The APT satellite images provided good weather information and adequate ice detection. The JRC marine radar slave display performed well during the tactical navigation exericise but requires more testing in the late season. The wet chemical developed film modification to the Canarctic downlink provided a much higher quality product than the previously used dry silver film. The softcopy display of airborne radar imagery was tested during the field trial and provided high resolution detail of ice conditions during the voyages. It was concluded that further development of an integrated softcopy system was warrented.

This report is the most recent work on the Shipboard Ice Navigation Support System (SINSS) under development by Canarctic Shipping. As such it represents the state of the art in the sphere of operations in ice.

The report describes the usefullness of this system in navigating the vessel around hazardous ice.

REFERENCE: de Heering, 1986.

TITLE: Proof of concept tests: data acquisition and analysis for close range ice hazard detection.

AUTHOR: de Heering, P.; Friberg, D.; Simpkin, P.

SOURCE: Transport Canada (TP6170E).

ABSTRACT:

An evaluation of a commercial fish-finding sonar in an iceberg detecting role was undertaken during July and August 1984, in the Davis Strait/Baffin Island region of the Canadian Arctic. A C-Tech CDS-40A sonar with an operating frequency of 36 KHZ was mounted within the hull of the icebreaking freighter, the M.V. ARCTIC, and lowered as required. The sonar was used in a program of sea trials during a 72-hour period on a voyage of the M.V. ARCTIC between Antwerp, Belgium and Nanisivik in Baffin Island.

The results suggest that a commercially available calibrated sonar system can be used to obtain quantitative and qualitative data which relate echo level (amplitude) to iceberg size. Measurements of echo level from ice pieces less than 100 tonnes and very large icebergs greater than 10 million tonnes indicate a range in values of target strength from 15 db to 35 db per square metre. Also, variations up to 40 db in target strength were obtained from multiple measurements on particular icebergs.

This report describes the initial trials undertaken to assess the potential for the use of sonar as a detection method for icebergs. Although of a preliminary nature the results were encouraging.

REFERENCE: Fissel, 1982.

TITLE: Major features of the summer near-surface circulation of western Baffin Bay, 1978 and 1979.

AUTHOR: Fissel, D.B., Lemon, D.D., Birch, J.R.

SOURCE: ARCTIC Volume 35 No. 1, March 1982.

ABSTRACT:

In the summer of 1978 and 1979, an extensive physical oceanographic programme was carried out in western Baffin Bay and Lancaster Sound. Data collected include satellite-tracked drifter measurements, CTD profiles and time series of sub-surface currents. They indicate that the near-surface circulation of the area is dominated by the southward-flowing Baffin Current. This current, observed to extend at least as far north as Lady Ann Strait (76°N) and south to Cape Dyer (67°N), is largely confined to within 100 km of the coastline. It varies in both intensity and width with the strongest flows occurring where the current follows a cyclonic intrusion into and out of eastern Lancaster Sound; here in the core of the current the median near-surface (4 to 11 m) speeds are 75 cm/s decreasing to 50 cm/s at 40 m depth, and 25 cm/s at 250 m depth. To the east of Devon, Bylot and Baffin Islands, the current is well defined but generally less intense with typical near-surface speeds of 30 cm/s. Important spatial variations occurred in the circulation of the area. In eastern Lancaster Sound two distinct and alternating flow patterns were observed in the strong intrusive current in the summer of 1979. Transient large scale meanders of the circulation were detected in a portion of the Baffin Current off the east coasts of Bylot and Baffin Islands. Between the eastern coastline of Bylot Island and the core of the southeasterly flowing Baffin Current, anticyclonic eddies of approximately 20 km in diameter occasionally occurred.

This article presented in ARCTIC Volume 35 No 1, presents the results of studies carried out in 1978 and 1979. It represents the most recent current information available for Baffin Bay.

REFERENCE: Intera, 1985.

TITLE: Advanced radar systems for support of Arctic marine operations.

AUTHOR: Mercer, J.B.; McAvoy, G.; Leavitt, E.; Lowry, R.

SOURCE: Intera Technologies Ltd. Polar Technical 1986, Vancouver, B.C.

ABSTRACT:

Several types of Arctic marine operations have benefitted over the past few years from advances made to airborne and ship or rig-mounted radars. This paper describes these radar systems, mainly in the context of three operations. These operations are:

1. Ice management support of exploratory drilling operations in the Beaufort Sea.

2. Seismic vessel support in the Beaufort Sea

3. Navigation support of the M.V. ARCTIC in the Northwest Passage.

The airborne radar description includes the utilization of Synthetic Aperture Radar (the STAR-1 system), its performance, the real-time capabilities, downlink and display. In particular, a new shipboard display system known as STAR-VUE is described.

The status of marine radars for ice detection and tracking from rigs and as navigation instruments on a transiting vessel are described, along with developments in the associated digital display technology.

This short paper is most useful as a quick reference on the subject of advanced radar systems. It is easy to read and understand.

REFERENCE: Lundberg, 1984.

TITLE: Mobile communicatins via satellite in the 1990's.

AUTHOR: Lundberg, O.

SOURCE: IMO

ABSTRACT:

The world's only satellite organization providing mobile communications on a commercial basis is the International Maritime Satellite Organization (INMARSAT). This paper reviews the origins of the organization and the needs of the shipping and offshore industry that led to its formation. The current system and its operations are described. The success achieved so far by INMARSAT in providing the satellite capacity for telephone, telex, facsimile and data communication to the maritime community makes it apparent that the system could also be used to provide capacity to the aeronautical community. Studies are now being made on future configurations of the system in which it may be possible to integrate a polar-orbiting satellite system, such as SARSAT-COSPAS. INMARSAT is proceeding with the procurement of a new series of satellites that would come into operation from 1988. This paper reviews the enhanced capabilities that these new satellites will provide in the context of the requirements for mobile communications via satellite in the next decade.

This paper explains in an elementary fashion the existing and future marine satellite communications systems as envisioned by the I.M.O.

REFERENCE: Melville, 1984.

TITLE: Lifesaving Equipment for Arctic ships.

AUTHOR: Holburn, J.G., Thompson, E.W.

SOURCE: Transport Canada (TP-6903-E).

ABSTRACT:

The Lifesaving Equipment Regulations of the Canada Shipping Act do not distinguish between the lifesaving equipment to be carried by vessels which operate in the Arctic from that required to be carried by similar vessels operating in temperate waters. The Canadian Regulations are not unique in this respect, as the Regulations of the I.M.O. Convention on Safety of Life at Sea (1974) and the recent amendments to Chapter III and the Regulations of the principal signators of the Convention do not treat ships which operate in the Arctic as a separate class.

The report discusses the implications of the current regulations and itemizes the deficiencies. Recommendations are made for changes to the regulations and new equipment is identified.

This comprehensive report is of primary concern to those involved in safety of personnel in Arctic ships. The report investigates the suitability of lifesaving equipment carried by ships trading in the Arctic. Deficiencies and shortcomings of the equipment are identified and solutions or alternatives are proposed. Of special interest is the section on additional equipment and survival craft.

REFERENCE: Melville, 1984.

TITLE: Personnel considerations in the safe operation of ships transiting the Canadian Arctic.

AUTHOR: Holburn, J., Thompson, E.W.

SOURCE: Transport Canada, 1984.

ABSTRACT:

This report covers a study carried out under DSS contact number 1SV83-00083 for Transport Canada, Ship Safety Branch; Canadian Coast Guard, on the functions and duties of ships' staff when navigating in Canadian Arctic waters. The objectives of the study are:

- to establish the factors and guidelines which should govern standards of manning, qualification, experience and training for shipboard personnel operating Arctic class vessels under all conditions,
- to develop operationally oriented navigational practices and procedures which should be carried out by the navigational watch members on Arctic class vessels in the different seasons and conditions.

REFERENCE: Melville, 1985.

TITLE: Special requirements for shipboard firefighting systems used in cold temperatures.

AUTHOR: Holburn, J.

SOURCE: Transport Canada (TP-6225-E).

ABSTRACT:

This report presents the results of a study to determine the effectiveness and suitability of shipboard fire extinguishing agents, systems and appliances, for use in very cold temperatures.

This report documents the environmental conditions which affect firefighting capability and identifies the firefighting problems which can arise. Procedures adopted by land based fire services to overcome cold temperature firefighting problems are included as are the protective measures adopted by shipowners and shipbuilders.

The firefighting and equipment standards and regulations for ships, offshore structures and helicopter decks of a number of national administrations are examined, and their cold temperature references compared.

A guideline specification for shipboard firefighting systems and equipment for cold temperature operations is presented, as are crew training requirements.

Based upon the study findings, recommendations are made for regulatory changes and proposals are put forward for further research required to resolve outstanding problems.

This exhaustive report is of primary concern to both regulatory bodies and operators of Arctic vessels. Investigations are made into current regulatory standards and many recommendations are made for improvements. The environmental conditions are well documented and problem areas identified.

REFERENCE: Melville, 1986.

TITLE: Marine crew survival in the Arctic.

AUTHOR: Holburn, J.G., Dick, R.A.

SOURCE: Transport Canada (TP-7348-E).

ABSTRACT:

This report examines the requirements of the Lifesaving Equipment Regulations of the Canada Shipping Act with a view to their applicability to Arctic ship operations with respect to survival equipment and supplies as distinct from appliances.

The report describes the potential ship abandonment scenarios in the Canadian Arctic and the consequent threats to crew survival and concludes that equipment required by the regulations is inadequate.

An evaluation is made of currently available survival equipment and suppliers, and equipment under development is identified. Crew survival equipment which should be carried by ships which operate in Arctic waters is recommended, together with tests which should be initiated. In addition, deficiencies in crew survival training (M.E.D.) are presented and suggestions are made on how they may be remedied.

This exhaustive report provides a good current overview. It is of special interest to those concerned with ship operations in Arctic waters. Of special interest is the concept for the equipment to be carried by Arctic class vessels. It is however, a paper study and should be read with that in mind.

REFERENCE: Miller Communication, 1985.

TITLE: Study of communications links for the northern distribution of processed ERS-1/Radarsat data.

AUTHOR: Yongacoglu, A.

SOURCE: Department of Supply and Services.

ABSTRACT:

RADARSAT is a radar-equipped Canadian remote-sensing satellite intended to be in orbit in the early 1990's. It will satisfy Canadian strategic needs for ice, iceberg, ship and ocean information over the Arctic and coastal economic zones, and for crop, forest, hydrological and geological mapping over the provinces and territories. The satellite will also provide global wheat crop assessments, global marine wind information, and the first radar stereo-geological map of the world.

The objective of this study is to investigate the means of implementing the communication links needed for the reliable distribution of processed RADARSAT SAR information.

This report is most useful, not only are RADARSAT links discussed and analysed, there is an extensive background to RF communications and their problems in high latitudes.

REFERENCE: Ryan, 1985.

TITLE: Assessment of marine radars for the detection of ice and icebergs.

AUTHOR: Ryan, J.

SOURCE: Transport Canada.

ABSTRACT:

In the winter of 1984 a comprehensive field program was undertaken to assess the iceberg detection capability of existing marine-type radars. The semi-submersible Sedco 706 drilling platform was selected for the trials. The Sedco 706 has four radar systems on-board two "X"-band (3 cm) and two "S"-band (10 cm), all manufactured by RACAL DECCA of Britain. One pair of the "X" and "S"-band systems comprise the RACAL DECCA FI 2459 combined (S/X) system which uses antennas that are co-located and synchronized. The complete system with "X" and "S"-band transmitter and receiver units is mounted on the top of the derrick at a height of 75 m. In addition, this system is equipped with low-noise receivers for increased sensitivity. The other "X" and "S" band systems are standard units with respective antenna heights of 45 and 35 m.

The data collected has proven useful in identifying the effect of critical environmental conditions, such as ducting and subrefraction, as well as providing valuable information on sea clutter. The calibration of the radar system has permitted the calculation of iceberg radar cross-sections and a normalized radar cross-section for the ocean in a wide range of sea conditions.

This report is most significant to the future possibilities of radar as an ice hazard detection tool. Although technical, there is a considerable amount of information for the less technically minded.

REFERENCE: Ryan, 1986.

TITLE: Enhancement of the radar detectability of icebergs.

AUTHOR: Ryan, J.

SOURCE: Transport Canada.

ABSTRACT:

A study has been undertaken to investigate the use of enhancement techniques to increase the radar dectability of icebergs. These techniques will permit more efficient use of iceberg management tools such as support vessels and aircraft. There are essentially two strategies to achieve enhancement available; namely, passive and active. Passive techniques refer to those which increase the icebergs effective echoing area or radar cross-section and include the deployment of reflective material on the iceberg surface as well as a number of reflector configurations based on balloon and kite systems. Active techniques include the use of radar transponders, radio direction finding equipment, radio navigation equipment and satellite tracking systems.

The study has demonstrated that passive techniques may be used to increase the probability of dectection of icebergs as well as increasing the detection or tracking range. The passive methods considered offer a very inexpensive way of improving iceberg tracking capability. These enhancement techniques will only be effective within the radar horizon.

This study is likely to be of more interest to the offshore drilling companies as the method of enhancement requires that the icebergs be first identified and then "seeded" by passive or active reflectors. The methods used are not considered feasable for general use.

2.4 Ship Design

2.4.1 Structure

SHIP STRUCTURE

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REFERENCE: Arctec, 1986

TITLE: The 1985 global ice impact tests on the USCGC POLAR SEA.

AUTHOR: Cowper, B.; Edgecombe, M.

SOURCE: Transport Canada, Transport Development Centre, Montreal.

ABSTRACT:

During September and October of 1985 the POLAR SEA conducted ice impact tests on heavily ridged ice features in the Alaskan portion of the Beaufort Sea. Bending strain gauge measurements were used to estimate the longitudinal bending moment distribution of the POLAR SEA during an impact with an ice pressure ridge. Compressive strains along the stem, and ship acceleration and velocity measurements were also recorded. This paper describes the methodology for determining the global ice impact force, and presents the corresponding results of these tests. A comparison of the results with other available data is also presented. Hull strain, and impact force time histories are presented, along with the longitudinal bending and shear distributions, during ice impact events. The results indicate that the methodology used in estimating the impact force is valid; and that full scale global load measurements provided an excellent understanding of ship/ice interaction.

One of only 4 ships (together with M.V.R. LEMEUR, M.V. KOGORIAK and M.V. ARCTIC) that has been properly instrumented to measure vertical impact force and hull response. forty rams were conducted, however, only a few were in effectively "infinite" ice. Largest force during a 9 knot impact.

REFERENCE: Arctec, 1985a.

TITLE: Review of proposed revision of the hull structural requirements of the ASPP Regulations.

AUTHOR: Daley, C.; Brown, R.

SOURCE: Canadian Coast Guard, TP6671E.

ABSTRACT:

This report contains proposed revisions to the Arctic Shipping Pollution Prevention Regulations (ASPPR), Hull Structural Requirements. The ship/ice collision risk model ASPEN is used to examine the current level of risk and set the design number of multi-year ice impacts. A parametric series of runs of the BAFFIN program (Arctec's Time Domain Ship/Ice Impact Model) is used to establish general force and stress equations for hull girder design. These values are compared to full scale and model data for the M.V. ARCTIC, KIGORIAK and ROBERT LEMEUR. Local ice pressure data from the POLAR SEA and KIGORIAK is used as the basis of a general local pressure algorithm. Line loads for use in design of frames, stringers, web frames, bulkheads and decks are derived. Proposed revised regulatory formula are presented (bow only). Example scantling for various ships are plotted and compared with current regulations. Finally an examination of the effect of current and proposed regulations on vessel deadweight and cargo volumes is made.

This discussion document was one of the starting points for the work of the CASPPR Update Committee. Revisions to the approach have been made.

REFERENCE: Arctec, 1985b.

TITLE: Parametric model study of M.V. ARCTIC hydroelastic response during multi-year ice impacts.

AUTHOR: Daley, C.G.; Phillips, L.D.

SOURCE: Transport Canada, Coast Guard Northern, TP6536E.

ABSTRACT:

This report presents methodology and results of a parametric model study of M.V. ARCTIC hydroelastic response during collision with multi-year ice. It describes physical modelling and documents development of a model test technology which represents the dynamic characteristics of M.V. ARCTIC. A flexible ship model composed of twelve segments is employed. Infinite multi year ice is simulated with Arctec Canada's MODICE blocks. Bow force components, bending stress and accelerations are measured. Variation in parameters is carried out. Analysis yields good agreement with available full scale trials data. Extrapolation of trends to M.V. ARCTIC design speed is shown and prediction equations for peak vertical bow fore sand maximum deck stress are derived. A Fourier transform methodology for prediction of vertical bow force on the basis of deck strain is experimentally proven, which allows extension to finite floe problems. A physical mechanism is formulated which explains ship response in terms of modal characteristics and forefoot geometry. The report concludes with an evaluation of the present study and recommendations for second phase development.

Represents the first study of ship/ice impact using a dynamic flexible model. Correlated with full scale data up to 4 kts. and extended to 10 knots. A soon to be released report of further work extends the speed range up to 16 kts.

REFERENCE: Arctec, 1985c.

TITLE: M.V. ARCTIC structural performance final report.

AUTHOR: Glen, I.F., Nawwar, A., Brown R.

SOURCE: Transportation Development Centre, TP5680E, April 1985.

ABSTRACT:

Analysis of the structural response data collected on board the M.V. ARCTIC during the 1979/81 operating seasons is reported.

The project was conducted in two phases, the first being identification of quality data and development of analysis procedure; and the second, reduction of the bulk of the data.

Worst loads were experienced while operating in up to 10/10th ice with multi-year floes present, being three to four times those experienced when operating in level ice. The large number of gauges permitted stress contours to be developed for each ship/ice interaction scenario, indicating areas of peak loading and their extent. Several cases of damage were also analyzed and loads up to 23 MN (2,340 tonnes) estimated as the cause. Analysis of measured stress in relation to Canadian Arctic Shipping Pollution Prevention Regulations indicated that plates are subject to a high proability of permanent damage, while main frames appear to have an adequate safety margin.

It is considered that the data collected, when combined with other technology in the field, has contributed to an understanding of the structural response of the vessel in ice and identified areas for future improvement.

Extensive statistical analysis of both magnitude and position of ice loads. Quality of raw data of some concern, due to gauge placement, sampling rate and lost channels. Extensive discussions and recommendations are valuable.

REFERENCE: Arctec, 1984

TITLE: Ice loads and ship response to ice USCG Polar Class 1982/83 deployment.

AUTHOR: St. John, J., Daley, C., Blount, H., Glen, I.

SOURCE: Transport Canada TP6039E, December 1984.

ABSTRACT:

This paper presents work toward development of local ice load criteria for icebreaking ships. A bow panel of approximately 100 ft^2 (9.1m^2) was instrumented, being divided into 60 sub-panel areas over which uniform pressures were calculated during each impact with ice. Finite element models of the hull structure were used to develop a data reduction matrix relating the measured strains to uniform pressures. Approximately 1400 events over a present threshold strain were recorded.

Extreme pressure-area curves were developed for each event, and extreme envelopes for each of five geographical areas. Trends in peak force and peak pressure are examined in terms of ship impact speed and ice conditions. Frequency-of-occurrence tables for highest average pressure are developed as a function of impact area for each geographical area. A statistical analysis of the extremes of the north Chukchi Sea data indicated that the peak pressure data followed a Gumbel extreme value distribution. Finally a non-dimensional analysis was performed on selected data, and an empirically based approach is presented for developing extreme pressure-area curves as a function of ice conditions, ship impact speeds, and the return period.

High quality, high quantity local ice pressure measurements. Statistical analysis of results.

REFERENCE: CANMAR, 1985.

TITLE: KIGORIAK and ROBERT LEMEUR 1983 impact tests, extended data analysis - final report.

AUTHOR: Canadian Marine Drilling Limited

SOURCE: Transport Canada, Coast Guard Northern.

ABSTRACT:

The work presented in this report is an extension to the work done in the original contract entitled "KIGORIAK and ROBERT LEMEUR Full Scale Ice Impact Tests".

The main objective of the project was to analyze all significant rams of the KIGORIAK and ROBERT LEMEUR 1983 ice impact tests to obtain a better understanding of the ship/ice interaction phenomenon during ramming by further investigation of the different methods of derivation of the bow force, further analysis of the ship response and examination of the relationships between the interacting parameters.

This is a report of the first properly instrumented measurement of global load measurement on ships. The tendency for load to drop off above 8 kts. is probably explained as weaker ice in higher speed impacts. The lack of ice data is the biggest weakness in this study.

REFERENCE: CANMAR, 1986.

TITLE: Proposed method for the derivation of structure of Class U icebreaking ships.

AUTHOR: Johansson, B.; Churcher, A

SOURCE: Canadian Coast Guard, June 1986.

ABSTRACT:

This report is a summary of the work undertaken in support of requirements arising from the discussions of the CASPPR Review Structures Subcommittee.

The first section sets out the proposed method of deriving structural scantlings for Class U ships together with worked examples.

Appendix 2A answers a series of questions of clarification from Coast Guard Northern. Appendix 2B is the derivation of Class U Section Modulus and Appendix 2C is the derivation of the factor A used in the method of calculation.

The second section deals with the behaviour of ice during the process of a ram from the point of view of ice mechanics.

The third section covers the data derived from the operation of the simulation model developed for the "Ship/Ice Interaction Energies" Project.

A proposal is made for rule hull girder modulus for a Class U (highest class) ship. The method is based on the addition of a ice impact modulus to a still water modulus. The proposal is made for discussion by the CASPPR Update Technical Subcommittee.

REFERENCE: Coburn.

TITLE: A rational basis for the selection of ice strengthening criteria for ships.

AUTHOR: Coburn, J.; DeBord, F.; Montgomery, J.;Nawwar, A.; Dane, K.

SOURCE: U.S. Ship Structure Committee Report No. SSC-309.

ABSTRACT:

A major consideration in the development of marine transportation for ice covered waters is the knowledge of the strength required for ship's hulls. Several classification societies and various government regulations provide guidelines for strengthening of ice-transiting ships. However, there are inconsistencies among these different guidelines, and ship have suffered hull damage from ice while operating in zones for which they were supposedly strengthened adequately. This report presents the results of a study to develop the basis for rational selection of ice strengthening criteria for vessels.

Volume I describes sources and differences between ice strengthening criteria in use by various classification societies, and Government regulations such as Canadian Arctic Pollution Prevention Regulations, Swedish-Finnish Winter Navigation Board Regulations. A comparison of the different criteria is presented on the basis of a relative weight and relative cost. Effectiveness of the criteria is evaluated on the basis of statistical ice damage data and on a sample of individual ice damage cases. In addition, a comparison of different materials and fabrication techniques used for ice strengthening is presented. Deficiencies in current ice strengthening procedures are identified and a rational procedure for selecting appropriate ice strengthening criteria is presented. In addition, recommendations for research needed to improve current ice strengthening criteria are described.

Volume II contains the appendices to the report including maximum and average ice conditions by month, tabular data, and a review of methods for damage analysis.

Provides extensive description and comparison of design guidelines. Suggests designing plating for deformation equal to its thickness. Suggests more work in the area of frame response, particularly collapse mechanisms due to instability.

REFERENCE: Daley, 1984a.

TITLE: Baffin - A dynamic ship/ice interaction model.

AUTHOR: Daley, C.G.

SOURCE: SNAME Ice Tech '84, Calgary.

ABSTRACT:

Ship/ice interaction is a complex process that is not yet well understood. Mathematical models serve to both develop and consolidate understanding of the problem. BAFFIN is a time domain simulation of the interaction, which uses the normal modes of the ship and the ice to compute a solution. This paper describes the background and assumptions of the program, and through a presentation of results for a range of ship and ice conditions discusses the essential aspects of ship/ice interaction.

User input to the program can be simple or elaborate depending on the available data. If results from a finite element program are available, then a complete description of the mode shapes and mode stress shapes can be input to BAFFIN. If these are unavailable, the program will assume values based on empirical relationships. The user is required to define the bow shape, ship velocity, ice strength and dimensions. As well the friction factor, depth of old imprints and level of damping are required.

The solution is arrived at by iteratively calculating an ice contact area, determining forces, accelerations, velocities and bow position at the next time step. A fourth order numerical integration scheme is used.

The output of the program is the force at the bow, the stress throughout the ship and motions of the ship. Complete output is presented for a variety of runs.

Description and results of a dynamic ship/ice interaction model. The actual calculation algorithm is given.

REFERENCE: Daley, 1984b.

TITLE: Analysis of extreme ice loads measured on USCGC POLAR SEA.

AUTHOR: Daley, C.G.; St. John, J.W.; Seibold, F.; Bayly, I.

SOURCE: SNAME Transactions, Vol. 92, 1984.

ABSTRACT:

Measured ice loads have been obtained from an instrumented panel on the bow of the USCGC POLAR SEA. The panel covers an area of 9.1 m and is capable of resolving pressures over an area of 0.15 m. During early 1983 the POLAR SEA conducted trials in the Bering, Chukchi, and Beaufort seas in level ice, pressure ridges, and thick multi-year ice. This paper presents an analysis of the ice forces and pressures based on probability. The data for thick multi-year ice are analyzed and presented for extreme-value statistics of pressure versus area. A theoretical model of the ship/ice impact interaction was used to extend the statistical relationships to ships of other sizes. A general algorithm, therefore, is proposed that describes the statistics of ice pressure as a function of ship displacement, velocity, and stem angle, valid for any ship in thick multi-year ice. The general formulation is extended to all types of sea ice through the analysis of non-dimensional ice loads for a range of ice thicknesses and ice strengths.

Summary of POLAR SEA program and statistical data. A general algorithm for ice loads on ships is presented.

REFERENCE: Det Norske Veritas, 1980.

TITLE: Rules for the classification of steel ships, Part 5, Chapter 1, ships for navigation in ice, January 1980.

AUTHOR: Det Norske Veritas

SOURCE: DNV, Veritasveien 1, 1322 Hovik, Norway

ABSTRACT:

The rules contain structural design guidelines for basic ice strengthening, ice strengthening for Northern Baltic, icebreakers and sealers.

The rules are traditional Baltic regulations.

REFERENCE: Dunne, 1977.

TITLE: Results of full scale ice impact load studies aboard CCGS NORMAN MCLEOD ROGERS.

AUTHOR: Dunne, M.; Edwards, R.; Noble, P.

SOURCE: POAC 1977.

ABSTRACT:

Before 1960, the St. Lawrence River up to Montreal was virtually closed to commercial navigation three months per year. However, with the implementation by the Federal Department of Transport of more efficient ice control and icebreaking measures, winter navigation had become a fait accompli in the late sixties.

To keep up with the high safety conditions prevailing in the System, the Department of Transport has to consider the development of new standards and guidelines which would form the basis of regulatory measures governing the movement of vessels in ice infested waters. As available information on the interaction between moving ice floes and vessels was scarce, the Departments initiated in 1974, an overall study of ice problems affecting the movement of ships in the Gulf of St. Lawrence and the St. Lawrence River and Estuary. The data obtained during the study will also have a direct application in hull design for ships operating in ice not only in the St. Lawrence System but also in Arctic waters.

The study included the assessment of ice conditions in critical reaches, the development of an analytical predictive model, full scale ice impact load acquisition and physical modelling of ice impact loading.

The next step in the program was to acquire full scale impact load date for St. Lawrence River ice conditions, preferable on a commercial vessel.

Because commercial ships normally avoid ice and actually spend very little of their total operational hours in ice, a decision was taken to use a Canadian Coast Guard Icebreaker as a surrogate for a commercial ship and to subject it to ice conditons similar to those which a commercial ship would encounter entering the St. Lawrence River. The intent was to install instrumentation in the ship which would permit the measurement of the external load encountered by the ship's hull during impact with an ice feature. This was accomplished by judiciously placing strain gauges on portions of the internal structure. During a calibration period, a known external force was to be applied to the hull to permit later estimation of external force by interpreting internal strains. Simultaneous with strain load measurements, initial ship speed, and ice characteristics were to be measured.

REFERENCE: El-Tahan, 1984.

TITLE: Strength of iceberg and artificial snow ice under high strain rates and impact loads.

AUTHOR: El-Tahn, H., Swamidas, A.S.I., Arockiasamy, M., Reddy, D.V.

SOURCE: 3rd International Symposium on Offshore Mechanics and Arctic Engineering, New Orleans, February 1984.

ABSTRACT:

The study examines the behaviour of iceberg and artificial snow ice under impact and multi-axial stress conditions, and the strength are measured under various strain rates and confining conditions. The properties and behaviour of artificial snow ice is compared with those of iceberg ice to see if the snow ice can be used as a substitute for iceberg ice when the latter is not available. Three types of tests were carried out on both types of ice, viz., uniaxial compressive, indentation and impact tests, and the results are presented. Density measurements and crystallographic analysis were also carried out on both snow and iceberg ice.

A representative (of many proprietary studies) report of experimental studies of iceberg impact pressures. Indentor pressures as high as 33 MPa in iceberg ice.

REFERENCE: Evans, 1982.

TITLE: Preliminary design estimation of hull girder response to slamming.

AUTHOR: Evans, J.H.

SOURCE: SNAME Transactions, Vol. 90, 1982.

ABSTRACT:

In an era of high-speed ships and tight schedules, it is important that hull girder whipping stresses be reckoned with. Studies with a proven lumped-mass model computer programme emphasize the importance of the slam center location and the distributions of ship and added masses. The distribution of bending stiffness (E1) is of less importance but has special significance for hull bending moments at about the ship's quarter-lengths. Variations in the magnitude of slam impact loading, ship mass, added mass and hull girder stiffness are shown to conform to the nondimensional relationships of dynamic load factor theory between bending moments and the ratio of slam duration to hull vibration period. Finally, a semi-empirical expression is presented which may be useful for estimating whipping bending moments amidships in the early stages of preliminary design.

While not concerned with ice loads, the discussion of dynamic response to impulsive loads is relevant.

REFERENCE: Finnish-Swedish Board of Navigation.

TITLE: Regulations for the strengthening and design of ships for navigation in ice.

AUTHOR: Finnish-Swedish Board of Navigation

SOURCE: Finnish-Swedish Board of Navigation (Draft).

ABSTRACT:

A draft of the proposed new Baltic Ice Class regulations covering ice class draught, engine output, hull strucutral design, rudder and steering arrangements, propeller shafts, beams, and miscellaneous machinery requirements.

The rules are explicitly stated as being based on Northern Baltic ice conditions. Ice bridging is considered. The ice load is assumed to be uniform in a strip of height "h", where "h" is at most .35 m. Elastic design formulas are used. Frames are designed against bending and shear.

REFERENCE: German & Milne; Technical Research Centre of Finland, 1985.

TITLE: M.V. ARCTIC dedicated field tests, ship/ice interaction - test results and analysis - final report.

AUTHOR: German & Milne and Technical Research Centre of Finland

SOURCE: Transport Canada

ABSTRACT:

The analysis of the dedicated field tests results has been carried out. Total bow ice load versus ramming speed has been examined. Formulae for total bow ice load/bow indentation relationship from measurements are given. From these pressure/area relationships are defined.

A comprehensive set of trials with 143 documented rams at speeds up to four knots. Represents the best available information on hull girder response in commercial transiting vessels.

REFERENCE: Gilmour, 1980.

TITLE: The corrosion of welds in icebreaking ships - a review.

AUTHOR: Gilmour, J.G.

SOURCE: Report MRP/PMRL 80-50 (TR), Physical Metallurgy Research Laboratories, Canada Centre for Mineral and Energy Technology, 1980.

ABSTRACT:

Literature related to the corrosion at the welds of icebreaking ships has been reviewed. Two distant types of corrosion - weld metal attack and weld heat affected zone attack - are described. Both types of attack are the results of small differences in corrosion potential between the corroding metal and the hull plate. The use of welding electrodes containing copper and nickel will eliminate weld metal corrosion and special hull steels are available that are claimed to reduce heat affected zone attack. A research project to assist the Canadian marine industry to minimize this problem is proposed.

A very brief review of weld corrosion in general. The paper summarizes future research needs.

REFERENCE: Glen, 1985.

TITLE: Analysis of the structure of the proposed CCG POLAR CLASS 8 icebreaker under extreme loads.

AUTHOR: Glen, I.F., Daley, C.G., Tam, G.

SOURCE: SNAME Transactions, Vol. 93, 1985.

ABSTRACT:

The Canadian Coast Guard is proposing the construction of a polar icebreaker to the standard of Class 8 under the Canadian Arctic Shipping Pollution Prevention Regulations (CASSPR). At 37,750 dwt and 75,000 kW (100,000 shp), this vessel will be the largest, most powerful icebreaker in the world. During the years of the design development, research into the Arctic environment and the behaviour of ships in ice covered waters has progressed considerably. In particular, a greater understanding of the extreme loads experienced by a vessel while transiting in heavy, multi year ice has been obtained through a number of ship instrumentation programmes, laboratory experiments and analytical studies. The evidence from this work indicates that the current CASPP regulations, which provide guidance on the minimum structural requirements for icebreaking vessels, may not be adequate to ensure continued long term safe and undamaged operation in heavy icebreaking conditions. The Canadian Coast Guard POLAR 8 Icebreaker Project Office therefore commissioned a review of the structural design of the proposal vessel under extreme ice impact loads and the very large propulsion power available. The study addressed, among other aspects, local structural response at the bow of the vessel as well as the total hull girder response under impact loads such as may be experienced during heavy ramming. This paper describes the rationale for the selection of the extreme ice loads on the hull, and presents a real application of recent experience in ship/ice interaction to a new design. In this respect, the paper not only proposes designing beyond the current regulation when designing to high ice classes for which there is no operating experience, but provides guidance on an appropriate technique for applying recent research results.

Contains a pressure versus area description of the ice load to be used in design. Suggests designing beyond the current CASPPR Class 10 requirements.

REFERENCE: Government of Canada.

TITLE: Arctic Shipping Pollution Prevention Regulations

AUTHOR: Government of Canada

SOURCE: Government of Canada, Canadian Coast Guard

ABSTRACT:

These regulate the structural machinery and other requirements for ships intended to navigate in Canadian Arctic waters. Ships are assigned class number designations from 1 to 10. The Arctic is divided into 16 shipping safety control zones. The permissible entry and exit dates for each zone is given in a table and is dependent on the class number of the ship.

These regulations were instituted in 1972 and are the only current regulations which are specifically designed for the Canadian Arctic. The regulations are currently under review and are expected to be updated in the near future.

REFERENCE: Hakala, 1980.

TITLE: Results from the statistical measuring system on board the M.V. ARCTIC.

AUTHOR: Hakala, M.; Riska, K.

SOURCE: Transport Canada.

ABSTRACT:

The ice-induced and wave-induced stresses in the hull, bow ice loads and the stresses in the bilge area were monitored during the normal operation of M.V. ARCTIC. The ship made four voyages to Nanisivik and/or Little Cornwallis Island during the measuring period of August to November, 1982. The first voyage passed in completing the instrumentation and the fourth voyage was not completed due to severe ice conditions.

For the conditions encountered, the open water hull girder loads were found to exceed the icebreaking loads. Frames and stringers were yielded, while the plating was not.

REFERENCE: Hughes, 1983.

TITLE: A rationally-based, computer aided, optimization approach.

AUTHOR: Hughes, O.F.

SOURCE: John Wiley & Sons, New York, 1983.

ABSTRACT:

For a structure as large and as complex as a ship there are three levels of structural design, the second and most central of which is the subject of this book. Concept design deals with the topology or overall geometry of the structure; preliminary design establishes the scantlings (structural dimensions) of all principal structural members; and detail design is concerned with local aspects such as joints, openings, and reinforcements. Overall structural geometry is generally determined by overall design requirements rather than by structural requirements, while detailed design is largely guided and constrained by fabrication methods and requirements. Also, since local structural details are numerous and basically similar among various structures they lend themselves to standardization and to design from handbooks and structural codes. Thus, it is in preliminary design where the structural designer has the largest number of significant decisions and options and the greatest scope for optimizing the structure so that it best fulfills the objectives and satisfies all of the various constraints and requirements.

A rationally-based design is design from first principles using the tools of modern engineering science. Thus, the rationally-based approach is ideally suited for preliminary structural design, and it is this approach and this level of design that is the subject of this book. As shown by some examples, this type of design offers substantial benefits to all parties concerned; owner, designer, builder, and operator.

An excellent modern reference on ship structural design. Of particular interest to this paper are chapters 9 through 16, which deal with elastic and plastic local structural analysis and design.

REFERENCE: Jones, 1976.

TITLE: Plastic behaviour of ship structures.

AUTHOR: Jones, N.

SOURCE: SNAME Transactions, Vol. 84, 1976.

ABSTRACT:

With the tendency toward more rational design procedures and optimum structures, higher speeds of marine vehicles, and increasing use of new materials, it is inevitable that plasticity must play a great role in naval architectural structures than in the past. This paper examines the static and dynamic plastic behaviour of rectangular plates and beams, and demonstrates how the simple theoretical predictions given provide insight into the surprisingly accurate estimates for the dynamic fracture of beams and cylindrical shells, and the slamming damage, collision protection, and ice damage of ships and marine vehicles. The paper concludes with an investigation of the longitudinal and transverse strengths of ships and marine vehicles.

This is a key paper, widely referenced, which discusses plastic design of shell plates. The paper looks at the cases of fully clamped and simply supported plates using a rigid perfectly plastic material.

REFERENCE: Karve, 1984.

TITLE: Structural design criteria for ice capable tankers.

AUTHOR: Karve, S.; Manoudakis, C.

SOURCE: Ship Structure Symposium '84, Arlington, Virginia.

ABSTRACT:

The focus of this paper is on the structural design criteria to be adapted in designing an ice capable tanker. Four structural design philosphies have been reviewed. These are:

- Elastic design of framing and plating
- Classification society rules
- Ship structure committee report no: SSC-309
- Elastic design of the framing and plastic design for plating

The above four philosophies have been evaluated in the structural design of an icebreaking tanker for a particular ice load. The analysis given in this paper is restricted to the bow area where the ice pressures are the highest. The framing system details and scantlings of a web frame and a panel spanning two web frames are given for each design approach. The four methods are then compared for Steel weight, ease of fabrication, and susceptibility to failure. Finally, recommendations are made on the basis of this comparison.

Uses plastic design for plating, but uses tenuous assumptions to arrive at a design equation. Discusses the proposal in the Ship Structure Committee Report No. 309. Suggests elastic design for framing. No design pressures are given.

REFERENCE: Kashteljan, 1968.

TITLE: Ice resistance to motion of a ship.

AUTHOR: Kashteljan, V.I., Poznjak, I.I., Ryvlin, A.J.

SOURCE: Sudostroenie, Leningrad (translation), 1968.

ABSTRACT:

To determine how model tests should be conducted to correctly scale ice resistance and to examine ice resistance for ships in continuous motion was studied.

The penetrativeness of the ship was defined as the characteristic describing the mobility of the ship in ice. It is measured by attainable velocity. Total ice resistance is broken into several components direct resistance from breaking ice and gravity forces, indirect resistance from pushing the ice pieces aside and the open water resistance. Icebreaking is described as taking place at the ice knife where there is local crushing and shearing of ice and then breaking by binding and at the hull sides where there is local crushing of the top layers until breaking occurs.

The breaking pattern of the ice is into cusp produced by radial cracks from the knife edge and concentric cracks produced by movement of the hull sides. The rows of cusps being broken increases as the ship's velocity increases. The number of floes is dependent on ice thickness, velocity and beam. Length to width ratio of floes is 3.5.

The breaking resistance is found as the potential energy of breaking ice divided by the distance travelled.

$$R_b = k_1 B \sigma h \mu o$$

where c is a function of hull shape.

The gravity resistance is composed of three parts: resistance from lift of icebreaker, resistance from submerging ice and resistance from turning ice pieces.

The most important component is that due to submergence so

$$R_2 = k_2 g \rho_i B h^2 \mu o$$

This includes the frictional losses between the ice and hull.

REFERENCE: Kashteljan, 1973.

TITLE: Methods of estimating the ice navigating capability of a ship in solid ice.

AUTHOR: Kashteljan, V.I.

SOURCE: The Navigational Qualities of Ships, edited by Kheysin, D. Ye, and Popov, Iv.N., Translation, CRREL TL417, pp 3-18. August 1973.

ABSTRACT:

Research to date in predicting ice resistance has been reviewed. The work of previous researchers, including Runneburg, Vinograd, Shimansky, Milano, White and Lewis and Edwards, is reviewed. The icebreaking is described as being composed of resistance at the stem, which is approximately 30% of the total resistance, and resistance at the sides. The stem continuously cuts the ice until the ice sectors are broken by the ship side sections directly adjoining the stem. Therefore, the limiting ice thickness is determined by thicknesses which can be broken by side sections.

Semi-empirical models are preferred to theoretical because the icebreaking process is random.

Operating indices, to compare the efficiencies of ships operating on continuous motion and in short runs were formulated. The capability in short runs was estimated by the condition that the entire kinetic energy of the ship is equal to the energy required to break an infinite strip. The length of a coasting run was used to characterize efficiency in continuous and ramming mode.

For continuous mode $E_1 = \left(\frac{N}{B}\right)^{1/2}$

For short runs $E_2 = \left(\frac{D}{B}\right)^{1/2}$

and for overall efficiency $E_3 = E_1 E_2 N^{1/2}$

where N is ship horsepower and D is tons.

Indices for comparing operational efficiency of ships in ice has been reviewed.

REFERENCE: Kashteljan, 1981.

TITLE: The effectiveness of the air bubbler system and conditions warranting its use by ships navigatng in ice.

AUTHOR: Kashteljan, I., Popov, Y.N., Tsoi, L.

SOURCE: AASRI, Leningrad, Vol. 376, 1981.

ABSTRACT:

At the end of the sixties the Finnish firm Wartsila developed and patented the air bubbler system. This was intended to improve the performance of ships in ice.

The operating prnciple of the bubbler system is as follows: Compressed air, delivered at a pressure just above the hydrostatic by a specially installed compressor, is led through a pipe system to underwater nozzles located along the ship's side in the forward part of the hull. Blown from the nozzles, the air rises to the surface, entraining water with it. The rising air/water stream repels the broken ice cover from the ship's sides and washes away snow and ice slurry. The resistance of ice against the hull is thereby reduced.

Another feature of the bubbler system is the possibility of using it as a bow thruster. Compressed air from the system can also be used for the rapid pressurising of heeling and trimming tanks in order to free a ship beset in the ice.

The bubbler system is less vulnerable and is more readily repaired at sea than a bow propeller, which produces a similar effect in washing away lumps of ice and repelling them from the hull.

The bubbler system was first installed in the ice class ship FINCARRIER and proven in the Baltic Sea in 1970. With the results of these trials Finnish specialists were able to evaluate the expediency of installing it in icebreakers and ice class ships for the improvement of their ice qualities.

These systems are currently fitted to seagoing icebreakers and ice class transports. They are also being fitted to inland waterways icebreakers.

REFERENCE: Kashteljan, 1984.

TITLE: Serial model trials of icebreakers differing in hull shape and main dimensions.

AUTHOR: Kashteljan, V.; Ilchuk, A.; Dedoshkin, R.

SOURCE: Proceedings, SNAME Ice Tech 84, Calgary, Vol. II, paper Q, May 1984.

ABSTRACT:

The influence of main dimensions and hull shape by performing serial tests at a 1:70 scale are determined. Tests were conducted in level ice maintaining similarity between ice thickness, ice density and ice friction coefficient. Parameters examined were length; beam; draft; stem, board, and design water line angles; entrance angle; stem angle; bow flare angle; and middle body flare angle. Ice resistance was most affected by bow flare angle. The other parameters, in order of their effect on resistance are the stem angle, entrance angle, beam, middle body flare angle and length. The draft had no effect on the ice resistance. Influence of hull parameters which can be used in the initial stages of design were obtained.

REFERENCE: Keinonen, 1983.

TITLE: Ice loads on ships in the Canadian Arctic.

AUTHOR: Keinonen, A.

SOURCE: West European Graduate Marine Technology Seminar (WEGEMT), 1983.

ABSTRACT:

In Canada during the last few years, the state-of-the-art of ice impact pressure and force determination has progressed rapidly.

This paper presents some of the main developments based on tests with Dome Petroleum's icebreaker CANMAR KIGORIAK. The new data suggests three changes (1, 2, 3) in the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR) and those changes should address the implications of two other (4, 5) findings:

1. A proposed increase of limiting local ice pressure in the ship's bow from 10.34 to 20 MPa;
2. A proposed addition of ice force carrying capacity requirements over large areas of the bow;
3. The introduction of global strength requirements for ship hull girders due to impacts with extreme ice features;
4. In impacts with extreme ice features, there is an important amount of dampening taking place which reduces the stress levels in the hull girder; and,
5. There is some evidence that scaling up the existing data from KIGORIAK to bigger ships will give relaxation to the global load requirements.

Presents some of the 1981 KIGORIAK test data (from Proprietary CANMAR Reports), and modifies the Johansson/Keinonen Ice Tech '81 paper Rule proposal. Points to the possibility of a force relaxation for impact speeds above 10 kts, due to change the global failure mechanisms.

REFERENCE: Kozasu, 1983.

TITLE: Metallurgical design and properties of structural steels for Arctic use.

AUTHOR: Kozasu, I.

SOURCE: Proceedings of the study session on "Fracture Toughness Evaluation of Steels for Arctic Marine Use", Ed. R. Thomson and C.S. Champion, CANMET, October 1983.

ABSTRACT:

This paper describes the metallurgical design and the properties of highly weldable as rolled 500 MPa steel plate for Arctic marine use. The metalurgical design consists of the following four building blocks:

- Intensified controlled rolling (ICR) where low reheating temperature and heavier rolling reductions near Ar_3 are emphasized.
- Transformation strengthening by alloying (for example, Cu+Ni) and/or on-line accelerated cooling (OLAC).
- Fine control of chemistry and impurities by advanced steelmaking technology.
- Considerations of weldability with respect to the cold cracking susceptibility and the toughness of the weldment welded by high heat input.

Microalloying elements (Nb, V and Ti) can be utilized to advantage in some instances. Care must be taken in the welding aspect in the cases of Nb. A favourable design is the low C-Mn system modified with Ni or Ni+Cu and with the low solute N system (low N, high Al-Ti) in combination with ICR+OLAC. When microalloying is applied, the addition is to be made preferably in an amount lower-than-conventional. A versatility in possible alloy designs which satisfy Arctic grade specifications is demonstrated in the production result. Further, detailed test results on both base plate and weldment prove a compatibility of such steels with the Arctic marine environment. This type of steel has been in use for icebreaking supply vessels and structures such as mobile Arctic caissons.

This paper contains quite a detailed and well referenced discussion of production techniques such as controlled rolling and accelerated cooling, and also of metallurgical design aspects.

The energy expended to push away floes is $k_3\ B^x\ hv^y\ 1/n_2$ where n_2 is an ice cutting coefficient dependent on the shape of the ice knife of the water line.

From model experiments with the Russian icebreaker ERMAK values for k_1, k_2 and y were found. k_3 and x were determined from full scale data.

$$- \quad R = 0.004\ B\sigma h u o + 3.6\ g\rho_i\ Bh^2\mu o + 0.25\ B^{1.65}\ hv\ 1/n_2$$

A description of icebreaking process for a ship in continuous motion in level, finely broken or coarsely broken ice has been given. A semi-empirical formula for icebreaking resistance broken into the several components of resistance as a function of ice thickness, velocity, beam and hull shape is also given. Friction between ice and ship is not directly accounted for.

The paper also includes a discussion on the resistance in finely broken ice (15-20 m) and in coarsely broken ice (20 - 2000 mm) and how this resistance is a total of the inertial resistance of the floes, dissipation resistance of ship's energy, static resistance from deformation of ice, and submersion and turning of the ice floes.

REFERENCE: Kujala.

TITLE: Parametric study of ship ramming multi-year ice.

AUTHOR: Kujala, P.

SOURCE: Coast Guard Northern.

ABSTRACT:

Ice loadings and hull response of a ship ramming a multi-year ice floe have previously been studied by a number of computer simulations and some full scale ramming tests. Results from simulations and full scale tests on M.V. ARCTIC match quite well with each other. However, earlier simulations were made only for one single ship and no other ship parameters except speed were varied.

In this study these parameters are varied systematically using a computer simulation model that is developed from that used in M.V. ARCTIC ramming simulations. The final goal of the study is to develop general formulae for the maximum bow force and bending moment when ramming multi-year ice.

This report shows extensive parametric exercising of the VTT mathematical ship/ice impact model. The bow shape used was a simple straight inclined wedge, and the simulations only were up to 4.5 kts.

REFERENCE: Lereim, 1983.

TITLE: Significance of fracture mechanics on design of offshore structures.

AUTHOR: Lereim, J.

SOURCE: International Conference "Fracture Prevention in Energy and Transport Systems", Rio de Janeiro, Brazil, November 1983.

ABSTRACT:

This work describes the demand and significance of fracture mechanics on the design of structures. The necessary strength assessments are reviewed, and the corresponding safety parameters are evaluated where the present results are highly representative for structural elements like plates, solid members, box girders and tubular members.

The paper discusses the application of fracture mechanics to a number of aspects of the design of offshore structures. There is a useful, though brief discussion of the applicability of fracture mechanics techniques.

REFERENCE: Lloyd's Register of Shipping.

TITLE: Proposed rules for the strengthening of ships intended to navigate in multi-year ice conditions.

AUTHOR: Lloyd's Register of Shipping

SOURCE: Lloyd's Register, 71 Fenchurch St. London, EC3M 4BS.

ABSTRACT:

This report contains the draft of the proposed addition to the Society's Rules to cater for ships intended to navigate in multi-year ice conditions.

The requirements for hull steel grades, Section 2.3 (pages 1 to 3) are intended to form a new Section 2.3 of Part 3, Chapter 2 of the Society's "Rules and Regulations for the Classification of Ships".

The requirements of Section 8 and Section 9 (pages 4 to 30) are intended to form a new Section 8 and to replace the existing Section 9 of Part 3, Chapter 9 of the Society's "Rules and Regulations for the Classification of Ships" respectively.

Contains both shear and bending design for frames. Has power and displacement influencing ice pressure. Has no pressure/area consideration in plate design. Background reasoning not available.

REFERENCE: Matsuishi, 1984.

TITLE: Ship/ice floe collision analysis considering the elastic deflection of hull girder.

AUTHOR: Matsuishi, M., et al

SOURCE: SNAME Ice Tech '84, Calgary, 1984.

ABSTRACT:

A larger icebreaking vessel has a longer natural period of vertical hull girder vibration, which, as it approaches the duration of ice impact force, amplifies the response in the longitudinal hull girder bending due to the resonance effect. For accurate evaluation of the ice impact force and the structural response, the elastic deflection of the hull girder must be taken into account in addition to the rigid body movement.

The authors developed a method of collision analysis using the finite element method. In the analysis the elastic bending and shearing deflections of the hull girder were considered as well as the rigid body movement of the ship. The equations of motion were solved by the time increment method. As the first step of the analysis, collisions of an icebreaking vessel with constant stem and entrance angles were calculated. Both the impact forces and structural response depend on the hull stiffness.

A finite element beam model, coupled with a simple ice penetration model was solved in a time step manner. The key parameter investigated was the hull girder stiffness and effect of variations on both force and response for impacts up to 17 knots.

REFERENCE: McLean, 1983.

TITLE: Canadian steel for Arctic application.

AUTHOR: McLean, A.

SOURCE: Proceedings of the Study Session on "Fracture Toughness Evaluation of Steels for Arctic Marine Use", Ed. R. Thomson and C.S. Champion, CANMET, October 1983.

ABSTRACT:

The control of O, S, P, N and H in steelmaking is reviewed from the perspective of the cleanliness and fracture toughness of the product. The extent of application of these controls in Canadian mills is briefly discussed, and emphasis is laid on the use of strategies that produce a 'fit-for-purpose' product having balanced properties for the Arctic and offshore environment.

The capabilities of Canadian mills in regard to the control of the elements mentioned in the abstract are reviewed. The paper has a good discussion on the way product toughness is influenced by process considerations.

REFERENCE: Melville 1985

TITLE: M.V. ARCTIC - midbody structure design.

AUTHOR: Baker, D.

SOURCE: Canarctic Shipping Limited.

ABSTRACT:

The M.V. ARCTIC was upgraded to a Class 4 icebreaker in accordance with the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR). The upgrading involved the strengthening of the midbody and the replacement of the existing bow. Melville Shipping Ltd. were contracted by Canarctic Shipping Company Limited to redesign the midbody of the M.V. ARCTIC. The redesign structure complies with the Class 4 notation, and an analysis used ice loads derived from observed conditions in the Canadian Arctic.

During the design process, the requirements of the CASPPR Class 4 notation were used as a minimum. Where the CASPPR requirements were considered inadequate, scantlings and arrangements were modified. Justification and calculations for any increase in scantlings are given when appropriate.

A good example of direct design for a difficult problem. An early example of CANMAR's design ice load (stepped triangular rather than the current straight triangular).

REFERENCE: Nibbering, 1983.

TITLE: Brittle fracture in fatigue loaded structures: influence of shock loads.

AUTHOR: Nibbering, J.

SOURCE: Proceedings of the Study Session on "Fracture Toughness Evaluation of Steels for Arctic Marine Use", Ed. R. Thomson and C.S. Champion, CANMET, October 1983.

ABSTRACT:

From the viewpoint of the risk of brittle fracture, small fatigue cracks may be just as dangerous as long ones, since it is the position of the tip of the crack that is critical. If the crack tip is situated in a welded region, it may encounter hard spots and so initiate a brittle fracture. Shock effects are particularly dangerous when fatigue shock loading only exist close to the point of impact. The 'residual' vibrations remote from the impact region are of significance only in terms of increasing the overall load on the structure. The high frequency components of these vibrations involve the general low stress increments. For the forebody of icebreaking ships, toughness evaluation tests should incorporate impact loading in such a way as to safeguard the structure against 'pop-in' phenomena.

The paper contains a good discussion of strain rate effects as they relate to ice impacts, and also of their effect on brittle fracture.

REFERENCE: Pellini, 1983.

TITLE: Selection of fracture criteria for steel structures in severe Arctic environments - application of guidelines system for fracture-safe design.

AUTHOR: Pellini, W.

SOURCE: Proceedings of the Study Session on "Fracture Toughness Evaluation of Steels for Arctic Marine Use", Ed. R. Thomson and C.S. Champion, CANMET, October 1983.

ABSTRACT:

This paper describes the importance of using rational principles of fracture analysis in the design of steel structures intended for Arctic service. Prevention of structural failure due to brittle fracture is an essential design factor for offshore fixed structures, mobile offshore drilling units, ships and other structures related to hydrocarbon recovery operations in Arctic regions.

These various structures are subjected to a wide range of loading conditions and service temperatures. The structural features include non-redundant structures that are fracture-critical with respect to a single structural member, and redundant structures that can develop total failure only if several members are fractured. The service loading conditions are significantly different for structures that are placed on land as compared to those that are located in water. Steel temperatures are limited to 30°F (-10°C) for the case of sea water immersion and may be -40°F (-40°C) to -60°F (-51°C) for the case of air exposure.

The paper cites that these various factors preclude the development of rational fracture control plans by the selection of steels based on a limited number of fracture test criteria. Existing rules and standards specify relatively few fracture criteria. The practice of relating these few fracture criteria to specific service temperatures does not resolve this problem. Any type of fracture test criteria must necessarily be related to service temperatures. The basic problem is that a wide variety of specific fracture criteria must be defined for: different types of structures; specific fracture-critical parts of the structures; land or water temperatures; and service loading factors that include significant loading rate differences.

Increasing the number of fracture test criteria, for the purpose of satisfying a wider variety of structural reliability requirements, does not provide a practical solution. The structural reliability significance for each of the fracture test criteria must be explained by the rules or standards documents. Increasing the number results in increased complexity for the explanation problem. The existing rules and standards provide very

limited or no explanations of the structural reliability significance of specified fracture criteria requirements. The designer is required to use the fracture test criteria by direction.

Use of different fracture tests for the purpose of providing a wider variety of fracture criteria, does not resolve the problem. Reasonable improvement in fracture criteria definitions may be made only if the additional, or replacement, fracture criteria satisfy requirements of direct interpretability to structural reliability requirements. How to interpret the signficance of fracture criteria is the key issue. There is only one way to achieve the interpretability objective. A fracure analysis system must be used. If such a system is not used, the designer cannot define the degree of structural reliability merit that is implied by specific fracture test criteria. Therefore, rational certification of the structural reliability merit to the user of the structure cannot be made.

The paper describes the application of modern principles of fracture-safe design that are based on design-by-analysis. The guidelines system for fracture-safe design is used as the example for procedures that should be used for selecting steels that satisfy specific structural reliability requirements. The first step involves defining fracture criteria requirements in structural terms. Fracture analysis is then used to define the fracture test criteria that satisfy the structural requirements.

The first part of this paper presents the primary features of the guidelines system for fracture-safe design. The role of fracture analysis in evolving fracture criteria for structures subjected to severe Arctic environments is described in the second part of the paper.

This paper is by one of the foremost workers in the field of structural integrity design in which engineering fracture mechanics is applied to fracture-safe and fatigue reliable design. A more general reference covering this material is: "Guidelines for fracture-safe and fatigue-reliable design of steel structures", William S. Pellini, published by the Welding Institute, U.K., 1983.

REFERENCE: Pense, 1983.

TITLE: Factors controlling fracture behaviour of cold temperature structures.

AUTHOR: Pense, A.W.

SOURCE: CANMET Conference, Ottawa, 1983.

ABSTRACT:

The control of fracture in engineering structures cannot rely solely on the selection of a material of high fracture resistance. Other aspects of the fracture control system, namely, design, fabrication and inspection, must be included along with the material considerations to provide both economy and safety. Proper control of design details and welding procedures may allow for the use of materials of more modest properties by reducing the initial defect sizes that must be tolerated and by reducing the potential for fatigue crack growth. Design and fabrication for inspectiability also increases the safety margin, as does the use of redundant design. When employed together, these factors, along with an appropriate material, will provide fracture control. Without them, even a material of high toughness may not do so. A brief review of some current work on microalloyed steels shows them to have attractive levels of strength and toughness for cold temperature service if the toughness level required is clearly specified to the supplier.

Useful paper which emphasizes the relationship of design and welding techniques as well as material properties to the reliability of the structure.

REFERENCE: Pisarski, 1983.

TITLE: The CTOD approach to the specification of fracture resistant welded steel structures for Arctic service.

AUTHOR: Pisarski, H.

SOURCE: Proceedings of the Study Session on "Fracture Toughness Evaluation of Steels for Arctic Marine Use", Ed. R. Thomson and C.S. Champion, CANMET, October 1983.

ABSTRACT:

This paper describes the way in which the crack tip opening displacement (CTOD) design curve approach may be used to ensure fracture resistance in structures intended for Arctic service. Testing techniques and, to a limited extent, analysis techniques, are described. Attention is drawn to the experience gained in the design and fabrication of North Sea structures which may be usefully employed in constructing offshore structures for Arctic environments. It is pointed out that fracture resistance is achieved not only by ensuring that materials are employed have acceptable toughness but also by the proper consideration of detailed design, service loadings, welding procedures, in service inspection and repair procedures.

The paper makes a case for the use of the CTOD design curve approach to fracture toughness evaluation for material selection purposes.

REFERENCE: Popov, 1968.

TITLE: Strength of ships navigating in ice, Leningrad, 1968.

AUTHOR: Popov, Y.N.

SOURCE: CRREL Translation TL123.

ABSTRACT:

This book deals with the theoretical problems and stress analysis of the hull structure of vessels which navigate in ice. It discusses the method of determining the loads which the ice exerts on the ship's hull, depending on the navigational conditions, strength characteristics of the ice, hull configuration, displacement and vessel speed.

The book presents the basic design methods to determine the internal stresses which arise in the elements of the hull structure due to the ice loads, and studies the design of these structures.

The book is intended for engineers, designers and scientific workers, who are in the field of ship-design. It can also prove useful to students and candidates whose speciality is shipbuilding.

A comprehensive discussion of ship/ice interaction and ship design. While the assumption of constant uniform ice pressure seems simplistic today, this is nonetheless a classic reference and is still valuable.

REFERENCE: Price, 1984.

TITLE: Welding developments for Arctic structures.

AUTHOR: Price, J.

SOURCE: Canadian Institute of Mining and Metallurgy, 23rd Annual Conference of Metallurgists, Quebec, August 1984.

ABSTRACT:

The paper reviews state-of-the-art welding processes and consumables for structural and pressure equipment applications in offshore environments particularly the Arctic. Optimum selection of consumables are discussed with regard to the facility to meet tentative toughness requirements in weldments. Finally, the development of welding procedure specifications are considered in relation to the prevention of hot or cold cracking and lamellar tearing.

REFERENCE: Rapo, 1983.

TITLE: Steel for Arctic use: classification requirements.

AUTHOR: Rapo, B.

SOURCE: Proceedings of the Study Session on "Fracture Toughness evaluation of steels for Arctic marine use", Ed. R. Thomson and C.S. Champion, CANMET, October 1983.

ABSTRACT:

The current published Rules of the Classification Societies covering first year ice conditions, as well as the Requirements as set forth in AWPPR, 1972, applicable to first and multi-year ice conditions, contain a wide range of requirements specifying constructional standards which are considered essential for operations in an ice environment. A notable omission in these publications is guidance for hull material selection. Acknowledging this situation, the objective of these notes is to set out a format for the selection of hull steel grades for ships intended to operate in Arctic conditions. Other equally important aspects such as the specification of welding consumables, the extent of non-destructive testing and the setting of acceptance and rejection criteria for welding defects also require to be addressed in depth but these were considered to be outside the intended scope of the present notes.

The paper summarizes the steel grades used on a number of Arctic vessels. The current Lloyd's practice in steel grade determination is outlined. Fracture toughness requirements are expressed in terms of Charpy V notch only; this is in contrast to the present trend towards the use of fracture mechanics concepts favoured by some.

REFERENCE: Rasanen, 1983.

TITLE: Steel selection for welded Arctic structures with particular reference to weld corrosion.

AUTHOR: Rasanen, E.O.

SOURCE: Steels for Offshore and Arctic Applications, CANMET Conference, Ottawa, July 1985.

ABSTRACT:

The paper surveys steel selection for Arctic steel structures primarily from the steel producer's point of view. "Safety Level" conceptions have been brought into use to describe dimensioning against brittle fracture. At the Safety Level I material properties, absence of defects and stress state of the welded joint are of decisive significance. At the Safety Levels II and III material properties of the parent steel is of decisive significance. These properties are measured by Pellini and DWIT tests. Welding problems form a very complicated optimization problem. To solve and avoid them suitable steel has to be selected for each application. Dimensioning against fatigue is related to crack propagation stage and it is not dependent on the strength of steel. The most difficult corrosion problems occurring in the zones of structures exposed to ice are presented in the paper. Particular reference is made to exceptional corrosion phenomena and research carried out by Rautaruukki Oy to prevent these phenomena.

A valuable paper which describes Finnish experience in the field of weld corrosion in Arctic ships and the use of various alloying elements.

REFERENCE: Ratzlasff, 1986.

TITLE: Behaviour and ultimate strength of continuous steel plates subjected to uniform transverse loads.

AUTHOR: Ratzlasff, K., Kennedy, D.

SOURCE: Canadian Journal of Civil Engineering, Vol. 13, No. 1, February 1986.

ABSTRACT:

The authors previously established that an initially flat rectangular steel plate, clamped on all four edges, displays three modes of behaviour as the intensity of a distributed transverse load increases: elastic flexural-membrane action, inelastic flexural-membrane action, and inelastic-membrane action.

For a long narrow plate, elastic flexural-membrane action exists up to the load at which yielding of the extreme fibres along the long edges occurs. Subsequent plastic hinge formation along the long edges reduces the stiffness. The second stage ends with complete yielding in tension along the long edges. From this point onward, the plate acts essentially as a membrane straining inelastically as yielding gradually progresses from both edges toward the centre. A lower bound to this behaviour is obtained by assuming the Poisson's ratio is the elastic value and the maximum membrane stress is the yield stress. A higher lower bound is obtained using the plastic value of Poisson's ratio. The load deflection curve gradually moves from the lower value to the higher and, because the edge forces can exceed yield, will finally exceed the latter, as confirmed by tests.

A finite element program modelling plane stress conditions, the inelastic Poisson's ratio, and the stress-strain behaviour to failure gave a load deflection response closely following the three predicted regions of behaviour. Two failure criteria have been established: a limiting tensile strain due to bending and tension at the edge and the shear resistance there. The behaviour and failure loads have been confirmed by two tests. Strain measurements taken during the tests substantiate, in general, the predicted behaviour.

Implications of using the ultimate strength of plates for the design of offshore structures for oil exploration and production in the Arctic are presented.

A very good description of the true behaviour of plates under lateral loads. Only uniform loads are discussed, with only fixed boundaries. A good discussion of the edge hinge. Comparison is made to an ADINA model.

REFERENCE: Riska, 1982.

TITLE: Assessment of the strength of the bow hull structure of M.V. ARCTIC under ice loads caused by multi-year ice.

AUTHOR: Riska, K.

SOURCE: Canadian Coast Guard, 1982.

ABSTRACT:

The response of the hull structure was analyzed with FE-method. Two areas were investigated; the most vulnerable structural elements in the fore peak and the shoulder area. The ice loads used are based on empirical relationship between ice pressure and loaded area. The strength assessment was done using Johnson-Ostenfeld criterion, which includes elastic and plastic buckling.

The main element found to be inadequate under the ice loads is the frame. The frames are considerable weaker than other structural elements, e.g. 30% of the strength of plating. The probable failure mode of the frames is the formation of plastic hinges.

Some stringers (#3 between frames 178 - 186, #4A between frames 188 - 192 and #6 between framed 1982 - 198) were also found to be inadequate. Other structural elements i.e. plating, other stringers and web frames maintain their load carrying capacity even though some local yield can occur.

In the head-on rams in multi-year ice floes the load area will not extend to the vulnerable areas of the bow. Thus the major hazard in head-on rams is the collapse of the frames. Stringer n:o 4A is on the possible contact area, but due to the supporting effect of the bulkheads on frames 188, 190 and 192 the total collapse is prevented.

Used a pressure/area design load of

$$P = 4.57\ A^{-.35}\ (\mathrm{MPa},\ \mathrm{m}^2)$$

corresponding to a return period of 400 rams. One problem was that the worst loaded area was obtained using a uniform pressure, rather than the peaked pressure/area distribution described. Low design pressures are offset by the use of elastic design.

REFERENCE: Sinha, 1984.

TITLE: Uniaxial compressive strength of first-year and multi-year ice.

AUTHOR: Sinha, N.

SOURCE: Canadian Journal of Civil Engineering, Vol. II, March 1984.

ABSTRACT:

Strain-rate and stress-rate sensitivity of the compressive strength of first-year columnar-grained ice, first year congealed frazil ice, and columnar-grained ice from an old floe have been investigated with load applied in the horizontal plane. In spite of similar salinity and density, the frazil ice proved to be considerably stronger than the columnar-grained ice. The strength of porous old floe ice with columnar-grained structure was very much the same as that of first-year ice of similar structure but the clear bulk ice of the old floe was strongest. Rate sensitivity of strength for the three types of saline ice was similar to that of fresh-water ice. Ductility of the old clear ice (as measured by the strain at upper yield) was the same as that of fresh-water ice; ductility of porous old ice was comparable to that of new frazil ice. New columnar-grained ice proved to be the most ductile material.

Results of testing at Mould Bay in 1981. A good current reference on uniaxial ice strength.

REFERENCE: Smith, 1985.

TITLE: Constant strain rate triaxial strength tests on multi-year ice.

AUTHOR: Smith, T.

SOURCE: National Research Council of Canada, Division of Building Research, November 1985.

ABSTRACT:

Geotech was contracted in March 1985 by the Division of Building Research, of the National Research Council of Canada to do a series of triaxial and uniaxial compression tests on samples of multi-year ice. The ice to be tested was five 30 cm cubes of multi-year ice from the eastern Canadian Arctic which were to be covered horizontally and vertically for testing. The triaxial compression tests were done at different stress ratios to gain a better understanding of the temperature and rate effects on the failure surface of multi-year ice in principal stress space.

Contains a good description of triaxial testing and results. Will serve as input to the interaction model being developed by Riska and Frederking.

REFERENCE: Soreida, 1983.

TITLE: Collapse analysis of ship shell structure.

AUTHOR: Soreida, T.

SOURCE: WEGEMT Conference, Helsinki University of Technology, 1983.

ABSTRACT:

The paper deals with capacity of stiffened ship shell panels subjected to lateral loads from ice. An introduction is given into the basis for plastic analysis of plated structures and collapse models for stiffeners and plate elements are presented. The stiffening effect from membrane forces is discussed and analytical models are described in which membrane forces are included. A brief description is given of nonlinear computer programs based upon the finite element method of analysis. These programs account for elasto-plastic material behaviour as well as the geometric effects of large deflections. The applicability of such programs is discussed and recommendations are given for design formulas.

Discusses non linear finite element analysis and recommends a design procedure, based on (Jones 1976) for the plating and three plastic hinges for the frames.

REFERENCE: Stern, 1985.

TITLE: Higher strength steels specially processed for high heat input welding.

AUTHOR: Stern, I., Wheatcroft, M., Ku, D.

SOURCE: Journal of Ship Production, Vol. 1, No. 4, pp. 222-237, November 1985.

ABSTRACT:

ABS Grade EH36 steel plates, specially formulated and produced with advanced metallurgical techniques are shown to have a significantly greater resistance to weld heat-affected zone (HAZ) degradation than conventional EH36 steel. Welds made in these steels with the electroslag welding process at high heat input rates retained adequate toughness in the heat affected zone at -4°F (-20°C); similar welds in conventional EH36 steel plate exhibit excessive HAZ toughness loss. This effect was confirmed on the basis of small-scale Charpy V-notch and large-scale explosion bulge testing. In view of their superior resistance to HAZ degradation, the steels should also be useful for applications where HAZ degradation is of particular concern, such as for American Bureau of Shipping, U.S. Coast Guard, and International Maritime Organization (IMO) weld requirements for liquefied gas carriers.

The paper describes the performance of modified versions of EH36 steel plate. The plate is designed such that it has adequate toughness in the HAZ.

REFERENCE: Timco, 1986.

TITLE: Confined compression tests: outlining the failure envelope of columnar sea ice.

AUTHOR: Timco, G., Frederking, R.

SOURCE: Cold Regions Science and Technology, No. 12, pp. 13-28, 1986.

ABSTRACT:

A series of confined compression tests has been performed on columnar sea ice over a range of nominal strain rates of 10^{-5} to 10^{-3} s^{-1} at a temperature of 02°C. Both the applied load and side confining load were measured. These are used to outline the full 3-dimensional failure envelope of the ice. The results are discussed in terms of loading rate effects, temperature, brine volume and air porosity. A strength index is introduced which correlates the present results in terms of these parameters. This leads to an empirical relationship which gives the functional dependent of the uni-axial compressive strength in terms of strain rate, loading direction, salinity, temperature and ice density. A mathematical description of the failure envelope is presented using a modified n-type yield function.

A very good discussion of confinement effects on mechanical properties of ice. Testing done during trials of POLARSTERN in northern Labrador. Influence of stress rate as well as strain rate discussed. No statistical analysis of results given. Contains 33 references.

REFERENCE: Tomin, 1983.

TITLE: Fracture mechanics approach to minimize risk of failure in steels for Arctic use.

AUTHOR: Tomin, M.

SOURCE: Proceedings of the Study Session on "Fracture Toughness Evaluation of Steels for Arctic Marine Use". Ed. R. Thomson and C.S. Champion, CANMET, October 1983.

ABSTRACT:

Level II risk analysis of fatigue crack propagation and brittle fracture is outlined. Uncertainties inherent in brittle fracture are divided into two groups: those affecting demand (stress-intensity factor) and those affecting capacity (fracture toughness). It is shown that local conditional probabilities of brittle fracture can be used in evaluating design aspects and materials selection for marine structures in Arctic conditions. The applicability of the approach outlined is demonstrated on an Ice Class vessel, the MV ARCTIC. Based on the results of the analysis, changes in the hull plating, ballast condition and design of bilge keel are recommended. Other aspects of risk-consequence analysis are also discussed.

A brief summary of the application of probabilistic fracture mechanics is given in this paper.

REFERENCE: Trudeau, 1983.

TITLE: Interim structural steel standards for Arctic class ships.

AUTHOR: Trudeau, L.

SOURCE: Proceedings of the Study Session on "Fracture Toughness Evaluation of Steels for Arctic Marine Use", Ed. R. Thomson and C.S. Champion, CANMET, October 1983.

ABSTRACT:

Canadian operational experience in the Arctic and Atlantic coast is reviewed from the viewpoint of the incidence of brittle fracture in hull plating. Against this background information, fracture concepts and testing methodology are discussed in some detail, relating field experience to the notch toughness characteristics of the grade of steel involved in the fracture or arrest event. It is suggested that as an interim position, bilge strakes of Grade E steel should be required for Arctic Class vessels irrespective of length; and that hull strengths in areas of potential ice-damage should be sufficient to resist severe denting. Quantitative proposals on design temperatures and material selection criteria are presented as a function of Arctic Class vessels.

The paper summarizes proposed guidelines for the selection of hull plate for Arctic Class ships, and presents the proposed interim steel requirements for the first time. Recommended steel grades for a given plate thickness and design temperature are given.

REFERENCE: Tunik, 1984.

TITLE: Dynamic ice loads on a ship.

AUTHOR: Tunik, A.

SOURCE: IAHR Ice Symposium, Hamburg, 1984.

ABSTRACT:

Dynamic ship/ice interactions have been considered for different scenarios of collision using a hydrodynamic model of solid/ice impact. As a result, the dynamic load parameters are expressed as products of their dimensional maximum magnitudes and dimensionless time history factors. The maximum ice load parameters are functions of masses and speed of collision, dynamic crushing properties of ice and geometry of the collided ship and ice. There are recommended design formulae and time history diagrams for many practically important cases of the ship/ice interaction, including ramming in an imprint of previous rams. The results can be used both for ice induced hull girder bending moment calculations and for stress analysis of local ship structure including appendages.

Views ice impact as a hydrodynamic extrusion process, with analytical solutions. This is based on older Russian papers and forms the basis for the proposed ABS rules.

REFERENCE: Tyson, 1982.

TITLE: Fracture control: current issues.

AUTHOR: Tyson, W.

SOURCE: Report ERP/PMRL 82-58(J), Physical Metallurgy Research Laboratories, CANMET, 1982.

ABSTRACT:

Essential features for current methods for materials testing and selection to prevent catastrophic fracture are summarized. An overview of linear-elastic and elastic-plastic toughness testing, and of 'initiation' and 'arrest' fracture criteria is presented.

A good, concise summary of the essentials of engineering fracture mechanics.

REFERENCE: U.S. Department of Commerce.

TITLE: S.S. MANHATTAN Arctic marine project. Notes from the 1969 MANHATTAN trials in the Northwest Passage, Appendix E.

AUTHOR:

SOURCE: U.S. Department of Commerce

ABSTRACT:

Two low speed (4, 5 kts) rams were conducted on an ice island in Barrow Strait in 1969 - The force was estimated from the pitch of the ship in the beached conditions and compared with analytical predictions. The imprint geometry was measured.

This is valuable data due to the displacement of the ship (150,000 T) and because it was an ice island ram. Imprint geometry and force estimates allow an estimate of the pressure/are function at the end of the ram.

REFERENCE: U.S.S.R. Register for Shipping, 1982.

TITLE: Rules for the classification and construction of seagoing ships
Part II, Hull, 1982.

AUTHOR: USSR Register of Shipping.

SOURCE: USSR Register of Shipping (Translation available from East-West Engineering Design Studies, Montreal).

ABSTRACT:

These (new in 1982) regulations cover the design of Russian arctic ships. Separate requirements are given for icebreakers (Classes LL1, LL2, LL3 and LL4) and Cargo Ship (Classes Y1A, YL, L1, L2 and L3).

These regulations calculate ice pressure based on bow shape, displacement and power. Plating and frames are designed against bending. Recommended bow shape and scantling parameters are given.

REFERENCE: Urabe.

TITLE: Steel selection system and reliability analysis of structures in cold regions.

AUTHOR: Urabe, N., Goskitake, A.

SOURCE: NKK Technical Research Centre, Japan.

ABSTRACT:

To make sure a safety performance of icebreakers or structures in cold regions, usual deterministic way to select steels is no longer applicable, since environmental conditions such as ice-structure interaction forces, and temperature, and even mechanical properties of steels show considerable scatter. Therefore, those variables must be considered as statistical manners.

In this paper we describe a method based on reliability analysis to select steels which should be used for the icebreakers and structures in the cold sea area. The method was also applied to analyse the safety assessment of the structures and to design a structure possessing both of fail security and economy.

Distribution functions of fracture toughness value of steels and imperfections inherently existing in the structures were surveyed by means of fracture toughness tests and non-destructive investigations, respectively. Uncertainties involved in each processes were cleared through probabilistic manipulations.

Finally, the probability of failure was quantified for the structures under given conditions. Imperfections which have not been detected by the NDI grow under fluctuation of the stresses, then the probability of the failure increased when service period was prolonged.

Reliability level for steel selection and for structure designing criterion was, then, determined by reflecting on the economy due to non-destructive investigation details, inspection interval and so on.

Useful paper describing a 'design-by-analysis approach to ship structures.

REFERENCE: Varsta, 1978.

TITLE: On plastic design of an ice-strengthened frame.

AUTHOR: Varsta, P., Droumev, I., Hakala M.

SOURCE: Winter Navigation Research Board, Research Report No. 27, 1978.

ABSTRACT:

Plastic design methods are applied to determine the load carrying capacity of the shell structure of an ice-going ship. The main object is the behaviour of the ice-strengthened frame, when the yield stress level is reached and exceeded. In the first part of this report quite simple analytical methods are used to study the various collapse mechanisms of the frame. The ultimate strength of the individual parts of the frame is determined and the total load carrying capacity is then calculated. The possibility of the lateral collapse of the frame is studied, too.

A non-linear three-dimensional finite element analysis is also carried out to study more exactly the behaviour of the frame and to check the validity of the simple analytical formulas. In the last part of this report, the results of structural model tests are compared with those of the analytical study and the finite element analysis.

This is a very comprehensive study of frame response. An important point is that the web of the frame was 20° off of perpendicular to the plate. The results pointed out that ductility and deflection, rather than fracture, dictated the ultimate load.

REFERENCE: Varsta, 1983.

TITLE: On the mechanics of ice load on ships in level ice in the Baltic sea.

AUTHOR: Varsta, P.

SOURCE: Technical Research Centre of Finland (VTT), No. 11, August 1983.

ABSTRACT:

The mechanics of the ice load induced by level ice-ship interaction is analyzed and a mathematical model for the load developed. The ice pressure which loads the ice wedge originates from the contact process between the ice edge and the ship hull. The dynamic bending of the ice plate induced by the contact force determines the ice load. The mechanical constants of the ice form the basic data for the analysis.

The mechanical constants of columnar-grained sea ice in the northern Baltic are evaluated partly by field tests and partly by data presented in the literature. The components for the macroscopic failure criterion of the columnar-grained ice are determined. The two cases: the three-dimensional and bending stress state are considered separately. A model for the average ice pressure is formulated. The ice pressure is assumed to consist of two nominal ice pressures. The effects of the stiffness of the shell structure and the crushing process are evaluated. The calculated ice pressure are compared with the measured ones on the full scale. For this purpose a special ice pressure gauge was designed.

A non-linear dynamic model for the bending of the ice wedge is presented. The solution is based on the finite element method. Both the ice wedge and the water under it are modelled. The mode super position approach is applied. An ice wedge is analyzed and the results are compared with data from two different full scale tests. The first one is a test with an artificial landing craft bow, the second being the ice load measurements onboard I.B. SISU. The effects of the speed of a ship and the ice thickness on the ice loads are investigated.

This work on the mechanics of the ice load does not include all aspects needed for ship design. The aim is to analyze ice loads in detail and develop a model to determine ice loads based on ice characteristics and ship particulars. The model forms a basis for future ice load measurement with which values for ship design can be gathered.

Dr. Varsta's Ph.D. theses. A compilation of many Baltic studies. Many failure processes discussed.

REFERENCE: Vaughan, 1986.

TITLE: Flexural response of icebreaking ships to impact loads.

AUTHOR: Vaughan, H.

SOURCE: RINA, 1986.

ABSTRACT:

In order to design an icebreaking ship, it is necessary to have a good understanding of the impact loads that the ship will experience in its chosen operating environment. The most reliable data are obtained by instrumenting existing ships and recording the response under controlled test conditions. Such tests have been carried out in the Canadian Arctic for about ten years, but selected results have been released only during the past two years. A brief review of available results is given.

The most extreme conditions from structural considerations occur when the ship rams heavy ice. The ship then experiences an initial impulse and subsequently beaches in a sagging condition on the ice. The bending stresses induced by the beaching motion were investigated quite generally by the author in a recent paper in the Transactions. However, depending on the flexibility of the ship and the geometry of the bow, it is possible that the dynamic response of the ship girder to the initial impulse can lead to bending stresses of the same order of magnitude as those induced by beaching. The problem has been examined by a number of other workers using finite element methods. In this paper, the author investigates the problem analytically and develops formulae which illustrate clearly the relative significance of ship flexibility on bending stresses during ramming.

An analytical treatment of the ship/ice impact problem, which predicts the first impulse force and the beaching force (no time history). While the approach is elegant and may lead to a solution, the ship dynamics and ice response are handled in possibly too simple a manner.

REFERENCE: Vuorio, 1979.

TITLE: Long term measurements of ice pressure and ice induced stresses on the icebreaker SISU in Winter 1978.

AUTHOR: Vuorio, J., Riska, K., Varsta, P.

SOURCE: Winter Navigation Research Board of Finland and Sweden, Report No. 28, April 1979.

ABSTRACT:

The aim of this report is to obtain relevant data for the dimensioning procedure of the shell structure of an ice-going vessel in the Baltic. The dimensioning ice loads have formerly been obtained by indirect methods because there is a lack of reliable analytical models of ice pressure and load and because so far empirical data of them is not available.

The only values published about ice loads are calculated indirectly from the response of the shell structure. The response is measured with strain gauges. This method does not give the value of ice pressure or load area, only an estimate of the total load. Thus it was decided to design a measuring system for local ice pressure.

Shows development of 'VARSTA' gauge, and collected ice pressure statistics in the Baltic.

2.4.2 Hull Design and Performance

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REFERENCE: Albery, 1984

TITLE: M.V. ARCTIC, ice transiting performance in continuous mode.

AUTHOR: Albery, A.C.R., Mathews, S.T., Macissac, B.D.

SOURCE: TDC, Report No. TP 5170E, May 1984.

ABSTRACT:

This report presents an analysis of the M.V. ARCTIC continuous ice transit data during commercial voyages and dedicated trials performed during 1979-81. The report provides a review of analytical and empirical models for prediction of level ice, broken ice and floe field performance. The authors examined the following equations.

- Kashteljan and modified Kashteljan
- Poznyak and Ionov
- Enkvist
- Carter
- Mathews

and recommended the following modified equation based on Poznyak and Ionov and modified coefficients empirically:

$$R_t = 0.035\ \sigma_f h^2 \mu_1 + 0.029\ \gamma_\Delta h B L \mu_2 + 7.4 \gamma_i B (H/L_v)^{0.5}\ h^2 \cdot V/\sqrt{gh}\ \mu_3 + R_{ow}$$

where σ_f = flexural strength

h = ice thickness

μ_1, μ_2, μ_3 = coefficients determined from bow angles, ship dimensions and friction factor

V = ship speed

B = ship beam

L = ship length

H = ship draft

γ_Δ = weight density of water less ice

R_{ow} = open water resistance

L_v = cubic root of volumetric displacement

REFERENCE: Arctec, 1984.

TITLE: M.V. ARCTIC ice transiting performance in the ramming mode.

AUTHOR: Nawwar, A., Goossens, L., Steele, M.

SOURCE: Transport Canada Report TP5320E, October 1984 (also Summary Report TP5321E).

ABSTRACT:

This report presents the methodology and results of a study of the M.V. ARCTIC ice transiting performance in the ramming mode. The report provides an account of ramming mode formulations which include resistance models, performance formulation and ship motions and accelerations. It describes the methods and instruments used in data scanning, categorization and quality assessment. A core database comprising dedicated trials of the Admiralty Inlet trials, 1981 was used as a basis for the analysis because of its higher quality. Data reduction and primary analysis were conducted on an HP9816 computer-based system. The data reduction algorithms are described including a comprehensive speed correction methodology. Results are presented in a standardized graphical format. The M.V. ARCTIC performance is analyzed and simulated. The analysis includes the effects of acceleration distance, speed of impact, thrust cut off, ice thickness, bubbler operation, trim condition and power level on performance. The latter is measured by average speed of advance and fuel consumption. The analysis also includes cycle time diagnosis. Performance simulation is presented for one model ram to demonstrate the applicability of simulation to analysis and optimization of the M.V. ARCTIC performance. The CASPPR power requirements, ship design features and instrumentation system has been evaluated. The report is concluded by recommendations for designers and operators of ARCTIC class cargo vessels, and for supplementary evaluation.

REFERENCE: Arctec, 1983.

TITLE: A semi-empirical ice resistance model.

AUTHOR: Lewis, J., Bulat, V., Glen, I., Kotras, T.

SOURCE: Transportation Development Centre, Transport Canada Report No. 4376E, April 1983.

ABSTRACT:

A large data base is compiled and used to determine the empirical approach of a ice resistance model.

Data was collected from full scale trials of 12 icebreakers for a total of 353 data points. The data was put into a form useful for optimization of the resistance prediction formulas. The resistance model is a variation of Naegle's model. Changes were made to add force components not considered by Naegle and allow icebreaking in more than three rows of cusps. Naegle's empirical constants were replaced with variables so that they could be optimized to the data. These include the L/D ratio of the cusps, the width of the ice crushing zone, area influenced by the bow pressure, and the percentage ventilation of the cusps. The variables were optimized numerically. The difference between predicted and actual resistance, the overall agreement of the model and the sensitivity of the optimized coefficients were analyzed. The coefficients showed significant variation from ship to ship and so they were regressed with respect to the ship's parameters. A method for calculating the thrust requirement for ice navigation of ships is outlined and forms a mathematical model of ice resistance to ships.

This model is believed to be the most advanced semi-empirical model to date. It is based on strong analytical basis, and involved comprehensive computational algorithm which has been derived and optimized from more than 350 data points obtained on 12 icebreaking ships and covering a wide range of conditions and ship characteristics.

REFERENCE: Arctec, 1978.

TITLE: Compilation and analysis of recent icebreaking model test data of a world-wide variety of hull forms.

AUTHOR: Nawwar, A., Edwards, R.

SOURCE: Transport Canada Report FR211C, January 1978.

ABSTRACT:

1275 data points are compiled for 35 different hulls. Through assessment of the various hull characteristics which may influence the icebreaking resistance and through statistical analysis, two models were derived from regression of dimensional and non-dimensional data. The formula consists of three basic components representing two function: ice fracturing and ice moving. Two equations were derived, one dimensional and one non-dimensional. In both equations the hull geometry is well represented. The dimensional equation was non-dimensionalized with one of the terms having to be scaled up from model data.

REFERENCE: Arctec, 1977.

TITLE: Results of full scale trials in ice to further assess the icebreaking capability of the CCGS WOLFE.

AUTHOR: Allan, R.J.

SOURCE: Report to TDC, TP1239, 1977.

ABSTRACT:

The full scale tests described in this report were part of a continuing project to evaluate the performance of the CCGS WOLFE.

REFERENCE: Baker, 1985.

TITLE: M.V. ARCTIC model tests.

AUTHOR: Baker, D.N.; Nishizaki, R.

SOURCE: Presented at the Eastern Canadian Section SNAME, November 1985.

ABSTRACT:

Major reconstruction work has recently been completed to convert the M.V. ARCTIC from a bulk carrier to an O.B.O. (Oil Bulk Ore) vessel. During the winter fo 1985/86 a new bow will be fitted to the vessel and the side shell structure modified. As a result of these modifications it is expected that the vessel will be equivalent to a ASPPR Class 4 ship.

Significant research and design effort has been invested in the development of the new arrangement and in particular the new bow form. Part of this design work involved model testing the existing hull form in three different ice tanks. This paper presents and discusses the results from this series of model tests.

REFERENCE: Baker, 1984.

TITLE: A new bow for the ARCTIC.

AUTHOR: Baker, D.N.; Nishizaki, R.

SOURCE: IAHR Symposium, Hamburg, 1984.

ABSTRACT:

This paper describes the design process and subsequent model testing of an improved bow design for the 28,000 DWT Canadian built bulk carrier M.V. ARCTIC. Open water testing was conducted at the National Research Council (NRC) in Canada and ice tank testing at the Hamburg Ship model basin (HSVA) in Germany. The data from the model tests are presented in the paper.

The test results showed the new bow to be considerably more efficient when breaking ice than the original bow and equally efficient when in open water.

REFERENCE: Carter, 1983.

TITLE: Ship resistance to continuous motion in level ice.

AUTHOR: Carter, D.S.

SOURCE: Transportation Development Center, Report TP-3679E, March 1983.

ABSTRACT:

To present an analytical method to evaluate ship resistance to continuous motion which can be used to predict resistance and optimize ship parameters was presented.

The ship forebody was represented by elliptical curves based on the bow angle, stem angle, and flare angle at maximum beam. The loads causing failure by crushing, buckling, and bending, were determined for a truncated wedge resting on the water. The quasi-static ice resistance conditions were broken into two parts: those relating to the stem and those relating to the sides. The ice resistance of the sides contained a frictional component. The direction of application of the resultant forces is found from trigonometric considerations. The ice was assumed to fail in wedges rather than cusps.

To transform the equation for static resistance into an equation for dynamic resistance a factor representing the effect of the upward pressure of the bow wave on the response of the floating wedge of ice was found. To do this several assumptions are made, the most important being that the wedge deflection is proportional to the bow wave.

The effect of internal ice pressure on the ship side was investigated and included in the final formulation but if data is lacking this term can be ignored. Also, a term to account for the friction of snow cover was found by regression analysis of full scale data.

A closed form, fairly simple and straight-forward analytical solution for resistance as a function of ship velocity, ice properites, and ship geometry was derived. The formulation can be used to find an optimum hull shape.

REFERENCE: Churcher, 1984.

TITLE: Operation, testing and design of vessels in the Canadian Beaufort Sea.

AUTHOR: Churcher, A.; Johansson, B.; Duff, J.

SOURCE: Draft Print, 1984.

ABSTRACT:

The normal procedure is to design, test and then operate. In the development of offshore support vessels for the Canadian Beaufort Sea, the process was somewhat reversed. Conventional vessels were initially asked to operate in an area of very different ice conditions. Operational experience and damage information was gathered. This data allowed test programs to be designed which gave a better understanding of the phenomena involved and lead to the development of design criteria specifically for the Beaufort Sea region. This paper deals with the areas of this process relating to ship safety, survivability and reliability; in particular, how these relate to hull structure, rudder strength and propulsion machinery.

REFERENCE: Churcher, 1984.

TITLE: Design of the ROBERT LEMEUR icebreaking supply ship.

AUTHOR: Churcher, A.; Kolomocjev, A.; Hubbard, G.

SOURCE: Marine Technology, Vol. 21, No. 2, 1984.

ABSTRACT:

This paper details the severe environment within which the ice vessel operates as well as the unusual operational profile. The design of the vessel is then traced identifying those areas which are of particular importance; namely, hull strength, selection of propulsion equipment, and selection of electrical and control equipment. The paper also discusses experience gained with the vessel in its first season of operation.

REFERENCE: DuBrovin, 1970.

TITLE: Calculation of broken ice resistance based on model testing.

AUTHOR: DuBrovin, D.V., translated by M. Aleksandrov and R. Moore

SOURCE: Department of Naval Architecture and Marine Engineering,
University of Michigan, April 1970.

ABSTRACT:

Behaviour of a ship in broken ice was modelled with 1:40, 1:50 and 1:60 scale models of icebreakers and a 1:50 scale model of a cargo tug and artificial ice of paraffin wax. Model data was collected as a function of ship Froude number. An empirical formula which was a function of ship parameters, friction coefficient, Froude number, a powering coefficient and two numerical coefficient which could be found by using an accompanying figure was obtained to describe ship resistance.

REFERENCE: Edwards, 1981.

TITLE: Results of full scale trials in ice of CCGS PIERRE RADISSON.

AUTHOR: Edwards, R.Y, Dunne, M.A., Johnson, B.

SOURCE: SNAME STAR Symposium, Ottawa 1981.

ABSTRACT:

This paper describes the results of extensive trials of the Canadian Coast Guard ship PIERRE RADISSON in Arctic ice conditions during July and August 1978, and in winter ice in the St. Lawrence River, Saguenay River and Gulf of St. Lawrence in February 1979.

The ship was found to perform extremely well under most conditions to which is was exposed, rivalling in performance with larger and more powerful ships.

REFERENCE: Edwards, 1976.

TITLE: Influence of major characteristics of icebreaker hulls on their powering requirements and manoeuvrability in ice.

AUTHOR: Edward, R.Y., Major, R.A., Kim, J.K., German, J.G., Lewis, J.W., Miller, D.R.

SOURCE: SNAME Annual Meeting, New York, November 1976.

ABSTRACT:

The Canadian Coast Guard has undertaken the design of a large polar icebreaker. To ensure that high performance in ice would be achieved in this ship, the Canadian Coast Guard commissioned a hull development programme to determine, through systematic tests in ice, the influence of designer-controlled variables such as beam, length, draft, block coefficient, and possibly hull-ice friction factor upon icebreaking performance and manoeuvrability, and to use the results of the experimental programme to select the major dimensions and propulsive power of the icebreaker. The programme was divided into four parts: a model/full scale correlation study; parametric ice resistance tests; assessment of icebreaker manoeuvrability; and selection of least cost hull parameters and power. In the course of the programme, correlation was demonstrated between model prediction techniques and full scale observations in ice thicknesses of up to six feet. Parametric ice resistance experiments revealed that draft and block coefficient exert a significant effect on icebreaker performance in level ice. A modified rotating arm experimental/analysis technique was developed to assess the manoeuvrability of ships in level ice. Model predictions of turning circle were found to reproduce full scale turning circle measurements well. Parametric manoeuvring model tests revealed that a steady state turning circle in level ice increases markedly with increasing ice thickness, ship length, and block coefficient. The ice resistance equation developed from the parametric test results was used in an optimization programme to provide the main dimensions, power and estimated cost of a least initial cost large polar icebreaker.

REFERENCE: Edwards, 1973.

TITLE: Comparative model tests of the icebreaker performance of two Canadian Coast Guard icebreakers.

AUTHOR: Edwards, R.Y., German, J.G., Lawrence, R.G.A.

SOURCE: POAC, University of Iceland, 1973.

ABSTRACT:

Icebreaking performance model tests described in this paper demonstrated that the hull form, incorporating amodern bow design, for a new design Canadian Coast Guard medium icebreaker, exhibits icebreaking performance superior to that of the CCGS NORMAN MCLEOD ROGERS. Furthermore, the model icebreaking performance data for this new design hull correlates well with existing model and full scale data for icebreakers with similar gross dimensions.

The icebreaking performance of the newly designed hull form (referred to as the "R" Class hull), was compared with that of CCGS NORMAN MCLEOD ROGERS in uniform plate ice and in mush ice, a compacted aggregate of finely broken ice typical of heavily trafficked canals, rivers and harbours. The measure of performance employed during these tests was the appendaged hull resistance as measured in a constant speed towing test.

1:36 scale models of the two icebreakers were towed at various constant speeds, side by side in model fields of uniformly thick "plate" ice. The "R" Class was tested at two drafts at zero trim. The ROGERS was tested at shallow draft at zero trim and at deep draft with sufficient trip to keep the plumb portion of her stem from encountering the ice cover. In the design draft condition, at speeds in excess of three knots, the resistance of the "R" Class was zero to 12 percent lower than that of the ROGERS for all ice thicknesses for which tests were conducted.

The resistance of the "R" Class in the deep draft condition was found to be between 10 and 16 percent lower than that of "R" Class at design draft. It was also determined that the resistance of the "R" Class in the deep draft condition was as much as 30 percent lower than that of the ROGERS for reasonable speeds and ice thicknesses. The tests indicate that the "R" Class icebreaker in deep draft condition with her propulsion plan producing 15,000 SHP is capable of maintaining a speed of advance of approximately three knots knots in three feet of uniformly thick lake ice.

The models of the "R" Class and ROGERS Class icebreakers were separately towed through fields of finely broken, compacted ice at various constant speeds. A comparison of the towing resistance for the two ships indicated that the resistance offered to the motion of the hull of the ROGERS at a speed of three knots is approximately 12 percent greater than that of the "R" Class in mush ice depths greater than three feet.

REFERENCE: Enkvist, 1972.

TITLE: On the resistance encountered by ships in the continuous mode of icebreaking.

AUTHOR: Enkvist, E.

SOURCE: Ph.D. Thesis, September 1972.

ABSTRACT:

To determine the parameters which are important in ice resistance and to improve methods of model testing analysis and full scale predictions from model results was the objective of this study.

Ice resistance for ships in the continuous mode of icebreaking is broken down into three components: resistance from breaking; submergence; and the hull velocity. To define breaking resistance, the forces necessary to break a simple cantilever beam and a semi-infinite plate, both on elastic foundations, are examined. It was concluded from model testing and theory that the horizontal ice force, the resistance due to pitching and the dynamic increase in foundation modulus, were all effects small enough to be ignored. The cusp breaking pattern was discussed. The breaking resistance is analyzed as energy divided by distance travelled. The total breaking resistance is a combination of pure breaking resistance and associated frictional resistance. The submergence resistance is defined as the energy required to statically submerge the ice. It is the only component which is affected by draft. This is only important at low speeds since at high speeds velocity effects take over. In the formulation, the submergence resistance is a function of mostly ship parameters; beam, draft, water plane area of the forebody, bow angles and entrance length. The velocity dependent resistance was broken into two components; resistance from turning the floes, which is an inertial force, and resistance from the ventilation of the floes which is a gravity force. Ventilation only occurs at high speeds and is a function of static pressure under the floe and the bow wave force. Hull angles are included in the resistance equation. Fifty to 70 percent of the total resistance is due to friction. Enkvist discusses the value of the friction coefficient and concludes that while the friction factor is influential, little is usually known about its value.

An analytical analysis, which mainly breaks down the ice resistance in level ice into three components and then analyzes each component separately and proposed a mathematical model based on physical phenomena, has been derived.

REFERENCE: Freitas, 1985.

TITLE: Model test of an ice class bulk carrier with the Thyssen/Waas bow form.

AUTHOR: Freitas, A., Nishizaki, R.S.

SOURCE: 4th International Offshore Mechanics and Arctic Engineering Symposium, 1985.

ABSTRACT:

Alternative bow forms have been investigated for the M.V. ARCTIC in a test programme sponsored by the German Ministry of Research and Technology and the Transportation Development Centre of Transport Canada. The M.V. ARCTIC is a Canadian Arctic Class 2 bulk carrier of 28,000 dwt which operates between the Northwest Territories and Europe during the summer and fall months.

The tests were conducted at the Hamburg Ship Model Basin using a 1:30 scale model fitted with three different forebody forms. These included the Thyssen/Waas design, a new design by Melville Shipping Ltd., Calgary, and the existing bow form. The tests were performed in ice, still water and irregular seaway.

REFERENCE: Freitas, 1983.

TITLE: Marine operations in the Arctic based on the Thyssen-Waas concept.

AUTHOR: Freitas, A.

SOURCE: Port and Ocean Engineering Under Arctic Conditions, 1983.

ABSTRACT:

The Thyssen-Waas icebreaker concept is a special forebody configuration with a novel icebreaking mode. The ice is broken in a defined manner, initially by shearing followed by bending fracture. The broken floes are displaced to the sides resulting in a well cleared track behind the vessel. Extensive model tests were performed at the Hamburg Ship Model Basin to develop the concept for various marine operations in ice covered waters. Among the vessels projected according to this system are an LNG tanker, a research vessel, an offshore supply vessel for arctic regions and an icebreaking pusher-tug for harbour and river operations. The development programme included systematic model tests in level ice and in ridges as well as in smooth water and in waves. The remarkable results of the model tests provided the incentive to prove the concept under natural ice conditions.

REFERENCE: Garrett, 1981.

TITLE: Conclusion from the first marine transit to Point Barrow in winter 1981 (by USCAC POLAR SEA).

AUTHOR: Garrett, R.

SOURCE: Offshore Technology Conference, Houson, Texas.

ABSTRACT:

A multi-year programme was initiated in 1979 to assess the operational feasibility of commerical marine activities in the ice covered waters of the Bering and Chukchi Seas. As part of the programme, the Coast Guard icebreaker POLAR SEA completed the first winter passage to Point Barrow, Alaska, in February 1981. This paper describes the results of the historic voyage of POLAR SEA and the environmental and ship performance data that were collected.

Numerous multi-year and first year pressure ridge profiles were obtained. The data indicates that a single representative multi-year pressure ridge model is not feasible due to the extreme variation in ridge shapes. This conclusion is at variance with some previously published papers.

POLAR SEA was heavily instrumented for the voyage. Ship performance was continuously monitored during the transit through 1,000 miles of ice on both magnetic and video tapes. Measured data included propulsion and ship motions parameters. A time lapse video recording system was used to document ice conditions. A casualty tc the steering gear and port propeller led to cancellation of some planned data collection and to initiation of a drift project in the Chukchi Sea.

Results from this third phase of the programme will be presented, including general plans for a 1982 winter deployment. The programme is jointly sponsored by a number of governmental and private sector organizations.

REFERENCE: German, 1975.

TITLE: Full scale testing in ice of three icebreakers.

AUTHOR: German, J.; Lawrence, R.

SOURCE: SNAME Ice Tech, 1975.

ABSTRACT:

In 1967 the Canadian Coast Guard commenced to use modelling techniques in the development and planning of new icebreakers. It was apparent that model testing and production techniques for full scale performance in ice, unlike open water techniques, was seriously lacking in actual full scale performance data for confirmation and correlation. Accordingly the Coast Guard undertook some full scale testing programmes as time and expediency permitted. Three such testing programmes are reported on in this paper, starting with CCGS WOLFE in 1969, LOUIS ST LAURENT in 1970 and LABRADOR in 1973. Up to now the results have not bee published. The results of full scale measured tests in ice are still woefully lacking and it is the purpose of this paper to help fill the gap by publishing these results.

Having occured over a span of several years and taken place for different purposes in widely different conditions, the test techniques and formats are not the same for the three sets of tests. The results presented are "raw", as developed at the time of the tests and have not been reworked.

REFERENCE: German, 1984.

TITLE: Hull form of icebreaker ships - background and progress.

AUTHOR: German, J.

SOURCE: CSSRA Conference, Montreal, February 1984.

ABSTRACT:

The evolution of icebreaker hull form design is traced, with explanations of its causes. The authors outline the principle advances with illustrations and comparative performance data.

The principles of penetration of ice cover are reviewed with discussion of how these principles have been applied in the hull form of icebreaking ships.

State of the art philosophy of icebreaker hullform design is discussed with some examples of significant variants and how operating and performance requirements lead to them.

REFERENCE: Gill, 1981.

TITLE: A ship transit model for passage through ice and its application to the Labrador area.

AUTHOR: Gill, R.J., Aboul-Azm, A., Terry, B.F., Russel, W.E.

SOURCE: SNAME STAR Symposium, Ottawa, June 1981.

ABSTRACT:

A transit time computer model for passage through pack and continuous ice is described, and the results of its application to offshore Labrador and Lake Melville are discussed. The model uses ice conditions which are digitized along a specific route and outputs total transit time for passages at various times during the ice season. The AES Ice Central Charts for 1969-79 were used in the model and were digitized along a route into Groswater Bay, Labrador, and through Lake Melville. Ice conditions from mid-December to late June were considered in the application. The model is based on icebreaking and ice resistance theory for movement in uniform continuous ice, pack ice and non-uniform ridged ice. The basic theories used in the model are due to Enkvist (1972), Kashteljan et al (1968), Vinogradow (1946) and White (1965). The model was run for three Canadian icebreaking vessels, the CCGS LOUIS S. ST. LAURENT and FRANKLIN and the icebreaking cargo ship M.V. ARCTIC, using ice conditions over a ten year period as reported by the Ice Central Charts. An application of the model to the voyage of the FRANKLIN to Lake Melville in March 1980 indicated good agreement in the actual and calculated transit times.

REFERENCE: Greisman, 1981.

TITLE: Brash ice behaviour.

AUTHOR: GREISMAN, P.

SOURCE: U.S. Coast Guard, Research and Development Centre, Report No. USCG-D-81, May 1981.

ABSTRACT:

Brash ice behaviour and its resistance to ships is described. Brash ice is defined as discrete pieces of ice 2 m or less in size. This behaviour is described as closely resembling that of a soil or Mohr-Coulomb solid. Its shear strength is proportional to the sum of the cohesion and normal stresses both multiplied by the friction angle.

The work by Mellor (1980) is reviewed and Greisman expands along this line of reasoning for non-zero ship speed.

From field observation it was noted that the brash ice behaved viscously.

Brash ice was produced in an experimental tank and a 1:10 scale model of an icebreaking tug was towed in the tank. As well, field data was collected from the same class of tug.

Four variables; resistance, ice thickness, velocity and ship length, are nondimensionalized. Through fit of the data an expression is found for R. It was found that below a certain speed the resistance was constant. For L = 140 ft, the critical velocity, Vc, was 0.12 ft/sec. Above this speed, the resistance was linearly proportional to ice thickness and proportional to the 3/2 power at length and ship speed.

Optimum speed is the critical velocity which was found to be 0.12 $\overline{gL}$.

REFERENCE: Ionov, 1984.

TITLE: Experimental studies on icebreaking ramming performance.

AUTHOR: Ionov, B.P.; Dubov, A.A.; Lednev, V.A.

SOURCE: SNAME Ice Tech 84, Paper R.

ABSTRACT:

This paper presents an excellent experimental treatment of the ramming of icebreakers. The authors analyzed full scale trials performed in pressure ridges, and used geometric averaging to characterize pressure ridges. They developed a kinematic analysis to determine the forces between the hull and ice during ramming, and used that in the analysis of full scale data. The following predictive formulae have been obtained for an icebreaker of 20-40,000 hp by approximation of experimental data;

$$\upsilon_c = 0.12\, S_f^{0.69} \quad [\,m/s\,]$$

$$S_{ice} = 0.035\, S_f^{1.1}\ (16.19 - 3.46 h_{sm}^{2}) \quad [\,m\,]$$

$$h_{sm}^{2} = 4.68 - 8.29\, \frac{S_{ice}}{S_f^{1.1}} \quad [\,m^2\,]$$

where ν_c = icebreaker impact velocity

S_f = acceleration distance

S_{ice} = length of section of smoothed ice thickness

h_{sm} = smoothed ice or ridge thickness

They also developed empirical formulation for cycle time analysis as a function of acceleration distance and smooth ice thickness.

Their experimental results appear to be in good agreement with other mathematical treatment reported almost simultaneously by Nawwar 1984.

REFERENCE: Kanerva, 1984.

TITLE: Icebreaking cargo ships.

AUTHOR: Kanerva, M., Lonnberg, B.

SOURCE: RINA Joint Evening Meeting, NECIES, October, 1984.

ABSTRACT:

A case study of a multi-purpose cargo ship designed for Soviet Arctic shipping is presented. Basic information for the project was data on Soviet Arctic traffic, the quantity and type of cargo, routes, existing vessels and icebreakers, experience of the traffic, environmental conditions (ice, snow, wind, etc.) and harbours. Some information was also available concerning factories, mills and other production facilities in Siberia and investments planned for the two next five-year periods. The project started in 1975, the contract for the first nine ships was signed in June 1980 and the first vessel was delivered in November 1982.

The background to the project is described and simulation of Arctic operation and economic comparisons of some alternatives are given. Design features and alternative propulsion systems are also discussed. Model testing of various alternatives in ice, in open water, in the cavitation tunnel and in rough seas commenced in 1978.

Comparisons of model test and hull scale measurements of open water trials indicate good correlation and generally very satisfactory behaviour of the vessel. Experience from the trials in ice in Siberian waters and comments after one year's service of the first three vessels are discussed in a separate section. A general description of the vessel is presented including the propulsion system, cargo-handling equipment, etc. and also some ideas on an icebreaking cargo vessel for the future.

REFERENCE: Keinonen, 1979.

TITLE: An analytical method of calculating the pure ridge resistance encountered by ships in first year ice ridges.

AUTHOR: Keinonen, A.

SOURCE: Helsinki University of Technology, Ship Hydrodynamics Laboratory, Report. No. 17, Otaniemi 1979.

ABSTRACT:

The resistance to ship's motion in first years ice ridges has been studied in this work. The ice resistance due to ridges is split into three components: level ice resistance, aging resistance and pure ridge resistance. The pure ridge resistance is solved analytically in the case of a large homogeneous ridge field with a constant thickness, based on shear breaking of the ridge.

The results have been compared with model test results for four models in homogeneous ridge fields and with ship test results for three ships in natural ridge fields. The model tests were made in the Wartsila Icebreaker Model Basin and the ship tests were performed by Wartsila.

The agreement between the experimental results for model tests and those obtained theoretically are generally good.

In ship tests deviations are found from -11 to +102 percent between experiment and theory. At this state of the art it is proposed that the deviations would mainly be due to the following:

- ridge characteristics are not known satisfactorily
- effects of deviations from theoretical idealization in ship tests in natural ridges are not known.

REFERENCE: Keinonen, 1978.

TITLE: An experimental model scale study on the compressible frictional and cohesive behaviour of broken ice mass.

AUTHOR: Keinonen, A., Nyman, T.

SOURCE: International Association of Hydraulic Research (IAHR) Symposium, Lulea, Sweden, pp. 335-353, 1978.

ABSTRACT:

The structure of a broken ice ridge was modelled and its mechanical properties determined.

A broken ice mass is described as being composed of blocks that are mainly 2 to 5 times the ice thickness. The ice pieces are larger than thick brash ice pieces yet smaller than large floes at spring break-up.

A model scale study of Baltic type ice ridges, which have a keel consisting mainly of loose ice blocks, was undertaken. The compressible, frictional and cohesive behaviour of the ice block was studied by means of shear, compression, kinematic, piling and so called plane tests. The kinematic tests were performed by pushing on the ice ridge with vertical and inclined plates. The resistance measured from these tests agreed with the predicted results although the data was quite scattered.

Results which can be used to calculate the pressure and ice ridge would exert against a ship have been determined.

REFERENCE: Kheysin, 1973.

TITLE: On the ice navigation speed of ships in extremely solid ice.

AUTHOR: Kheysin, D. Y.

SOURCE: The Navigational Qualities of Ships, edited by Kheysin, D.Y. and Popov I.N., Translation CRREL TL 417, pp. 19-30.

ABSTRACT:

The paper describes ice resistance for ships in the ramming mode. Probability methods are used and reaction of the ship is considered to be a random process. Probability of stoppage is computed. To compare ships of differing hull shapes, an equation is derived for the dimensionless magnitude of the dispersion of the force of direct resistance.

REFERENCE: Kitazawa, 1985.

TITLE: Resistance to ship hull-motion through brash ice.

AUTHOR: Kitazawa, T., Ettema, R.

SOURCE: Cold Regions Science and Technology, Vol. 10, No. 3, April 1985.

ABSTRACT:

Brash ice is defined as ice fragments typically less than 2 m in diameter. Previous formulas for predicting brash ice resistance are reviewed. Experimental results from model tests of a 1/40th scale tanker are presented. Two different bows, a wedge bow and a simplified icebreaker bow were tested. Ice thickness and channel width were varied. The results are presented for model scale only and are compared to several existing formulas. Some qualitative conclusions are drawn on the influence of various parameters and resistance components are identified. It was found that resistance is almost linearly proportional to brash ice layer thickness. No attempt at predicting full scale resistance was made.

REFERENCE: Kloppenburg, 1975.

TITLE: Ice resistance of a cargo vessel in the continuous mode of icebreaking: test of three geosim models in ice.

AUTHOR: Kloppenburg, M.

SOURCE: Proceedings, SNAME Ice Tech, April 1975.

ABSTRACT:

The same ship, a cargo vessel was tested at three different scales: 1:65, 1:50; 1:35. During the tests the E/ ratio of the ice was kept constant rather than properly scaling . Three prediction formulas, from Lewis and Edwards, SNAME, 1970; Edwards and Lewis, 1973; and Vance, 1974; were compared to the test results and that of Lewis and Edwards 1970 was found to be the best.

An expanded empirical resistance formula was derived and through regression analysis the coefficient were determined:

$$R_I = C_1 \sigma h^2 + C_2 \rho_w g B h^2 + C_3 \rho_w B h V^2 + C_4 \sigma B h + C_5 \rho_w \rho B T h$$
$$+ C_6 \rho_w \, B V \sqrt{g h^3} + C_7 \rho_w \, B V h \sqrt{g B}$$

The gravitational forces (from the change in potential energy of the broken ice) was the largest force acting on the ship.

Two of the models were segmented transversely and it was found that the ship length only slightly influences the total resistance.

Validation of previous semi-empirical formulas and consistent results from models of different scale were studied.

REFERENCE: Kotras, 1986.

TITLE: Comparison of USCG POLAR CLASS icebreaking patterns: full scale trials, physical model tests and analytical predictions.

AUTHOR: Kotras, T., Humphreys, D., Ettema, R., Free, A.

SOURCE: 21st American Towing Tank Conference, Washington, D.C., August 1986.

ABSTRACT:

The paper presents an attempt to compare model scale and sparse fulls scale data on patterns and piece size. Analytical predictions are made using the SPLICE MODEL. The model uses a cusp model with several rows. Data from full scale observations on several icebreaking trials have been used to develop a cusp depth, D_c, model in the form:

$$\frac{D_c}{K_1 l_c} = \frac{1}{2.4 + 6.0\,v}$$

where $K_1 = 50.7\,n_3^2 - 64.5\,n_3 + 21.3$

n_3 = average direction cosine over forward 20% of the ship's length

l_c = characteristic length of the ice

$v = (\sin\alpha/\tan\beta')\cdot(v/\sqrt{g l_c})$

α = hull waterline angle at centre of cusp

β' = normal flare angle at centre of cusp

The model agrees with data from the trials of the Polar Class icebreaker trials.

REFERENCE: Lewis, 1982.

TITLE: Resistance and propulsion of ice-worthy ships.

AUTHOR: Lewis, J., deBord, F., Bulat, V.

SOURCE: Proceedings, SNAME Annual Meeting, New York, November 1982.

ABSTRACT:

Data from several full-scale ice trials and from corresponding model tests have been collected. In many instances, these trials and model tests have been performed at different times and by different organizations with the result that no consistent analysis of the data have been made. In this paper, such an analysis is made. Its purpose is to reveal information regarding propulsion factors as well as hull resistance factors. Thrust deduction, wake fraction, and relative rotative efficiency are analyzed in detail for tugboats and icebreakers in open water to show how greatly these coefficients differ during towing conditions from free-running conditions. The coefficients are then examined under icebreaking conditions using ice and open water ship trials data as well as ice and open-water model test data. The propulsion-oriented analysis of the data leads to a method for inferring hull ice resistance from ice trials data and this method is consistently applied to all trials data. The resistance is divided into two components: a speed dependent and a speed independent term. The total ice resistance is non-dimensionalized by dividing it by $p\ gBh$ and then the simple two terms of the resistance equation, $C_o h$ and $C_1 hV$ are manipulated to get dimensionless equivalents. The equation does not account for ice strength, hull form, or friction coefficient in order that the influence of the other factors could be determined. To include all the parameters a third coefficient was added to the equation and values for all three coefficients were found through a multiple linear regression. The trials resistance data are then compared with those from model ice resistance tests and it is shown that 63 percent of all trials data lie within ± 20 percent of values predicted by model test data. Past model data in which hull form was purposefully varied are reviewed as well as a new analytical method for predicting hull resistance. The propulsion and hull data analyses are then combined to provide insight into new methods for selecting major propeller parameters during the design stage.

REFERENCE: Lewis, 1970.

TITLE: Methods for predicting icebreaking and ice resistance characteristics of icebreakers.

AUTHOR: Lewis, J., Edwards, R.

SOURCE: Proceedings, SNAME Annual Meeting, New York, Paper No. 5, November 1970.

ABSTRACT:

The work of previous researchers is reviewed. A substantial amount of experimental data on continuous and ramming mode data is reduced to a common base through non-dimensional analysis. The reduced data is analyzed using statistical methods to produce semi-empirical relationships for icebreaking in the continuous and in the ramming mode. The relationships are a function of ice and ship parameters and can be used to determine the power required for a ship to proceed at a given velocity through a given thickness of ice. The predictive relationships are compared to separately analyzed full scale data and the agreement is good:

$$R_{ice} = C_0 \sigma h^2 + C_1 \rho_i g B h^2 + C_2 \rho_i B h v^2$$

where the terms of R_{ice} represent the breaking plus friction resistance, buoyancy plus friction forces, and the momentum interchange between the ship and the broken ice respectively and the coefficients are determined from regression analysis of the model data.

REFERENCE: Makinen, 1977.

TITLE: Ice navigation capabilities of Lunni-Class icebreaking tankers.

AUTHOR: Makinen, E., Raimo, R.

SOURCE: SNAME Eastern Canadian Section, Montreal, 1977.

ABSTRACT:

Even in mild winters, all Finnish ports are ice-bound for part of the year. As about 85% of the Finnish foreign trade is carried by sea, ice navigation is a question of national necessity. The maps in Figure 1 show the ice conditions in the Baltic in typical mild, normal and severe winters, at the time of the maximum ice extent during each year.

Finnish ice navigation has a long history. The operation by SS EXPRESS between Finland and Sweden in 1877 is regarded as the beginning of winter ice traffic in Finland, so that winter navigation has its 100th anniversary this year.

Tradition and the need for ice navigation have both greatly promoted the development of icebreaking technology and icebreaking operations in Finland. The Finnish authorities, shipowners and shipbuilders have all been involved in this work.

REFERENCE: Makinen, 1975.

TITLE: Influence of friction on ice resistance: search for low friction surfaces.

AUTHOR: Makinen, E., Lahti, A., Rimppi, M.

SOURCE: Proceedings, SNAME Ice Tech 75, Montreal, April 1975.

ABSTRACT:

An investigation of ships' icebreaking properties has proved the dominant significance of hull surface treatment, i.e. mechanical friction, on ice resistance. The influence of the hull surface quality on ice resistance has been measured both in model tests and on ship scale by testing ships with the same dimensions and hull forms but with different types of hull coatings. Many materials have been investigated in order to find a hull coating which is smooth enough and which is not worn off by ice-blocks. The critical area actually exposed to the damaging effects of ice is a relatively narrow zone around the waterline. The ice-abrasion resistance of several two component coating systems was tested on icebreakers. According to the results some epoxy coatings seem to stand the severe abrasion outstandingly well. Another means of obtaining a smooth surface is the use of stainless steel in the critical area, but galvanic corrosion brings difficulties which are hard to overcome. Coatings are only described qualitatively: no numbers are put to the friction coefficients.

REFERENCE: Mathews, 1984.

TITLE: M.V. ARCTIC ice transiting performance in continuous mode,
Appendix C.

AUTHOR: Mathews, S.

SOURCE: Transportation Development Centre, Transport Canada, Report
TP-5170E, May 1984.

ABSTRACT:

Determine a semi-empirical equation from dynamic considerations in a manner similar to resistance equations used in fluid mechanics for ship resistance in continuous icebreaking mode was determined. Ice resistance is broken into two components:

1. resistance to ice,

2. resistance from the ship submerging and moving the ice and the frictional forces as a result of the ice moving against the hull.

Each component is a function of ship speed and other parameters thought to be important to icebreaking. Exponents of the parameters are determined from the experimental data and from the conclusions of previous researchers. Each component has a coefficient: A the coefficient of the icebreaking resistance is a constant for any hull form, G is the coefficient of ice sumbergence, movement and frictional resistance. G is the multiplication of two factors - one, G_o is constant for a particular ship while 1 + m is determined for each ship by the coefficient of friction and m, the longitudinal direction factor of a tangential forces. Provided that a model friction coefficient is known experimental data from model testing must be correlated as a function of resistance and velocity in order to determine the values of the other coefficients. This has been done by the author for the MV ARCTIC using iterative regression analysis. Other input parameters needed are ice properties (tensile strength in flexure, modulus of elasticity, density and thickness) beam of the ship and full size friction coefficient.

Resistance as a function of ship speed is given. Predictions of resistance versus speed can be made for any ship if experimental data on model icebreaking is available and if friction coefficients can be estimated for the model and full size ship.

$$R_i = \frac{A\ \sigma\ bh^{1.5}\ g^{.5}}{(E/\rho_i)^{.5}\ V^{.5}} + G_o \rho_i g^{.5}\ bh^{1.5} (E/\rho_i)^{.25}\ V^{.5} (1 + m\mu)$$

REFERENCE: Mathews, 1975.

TITLE: Aspects of the propulsion power of Arctic vessels, considering their operating environment.

AUTHOR: Mathews, S.T.

SOURCE: SNAME Ice Tech, 1975.

ABSTRACT:

The paper applies ice resistance technology to the calculation of design powers and icebreaking performance. There are five main sections:

1. Operating environment and ship classes - reference is made to the Canadian Government Arctic Shipping Pollution Prevention Regulations and the Ship Classes Zones and Seasons as these items are connected with the environment. A description is also given of conditions during the severe ice season in zone 13 when an experimental voyage was in progress.

2. Ice resistance, inertial ice breaking capability (penetration on stopping), thrust and power - an exact formula is developed for the penetration on stopping. This is related to ship speed and a minimum value proposed for design purposes. The present status of ice resistance technology is described in this section.

3. Minimum design power calculations for various ships - the results developed in section 2 are applied to assess the icebreaking capabilities of the vessels.

4. Arctic Class numbers - the icebreaking capabilities calculated in section 3 are related to the ship Classes.

5. Concluding remarks - a summary is made of the main points brought out in the other sections and suggestions are made for various formulae as design guides. The need for continued model and full scale research and for operations data is indicated.

REFERENCE: Melberg, 1970.

TITLE: The design of polar icebreakers.

AUTHOR: Melberg, L., Lewis, J., Edwards, R., Taylor, R., Voelker, R.

SOURCE: SNAME Paper No. 2, presented at Spring Meeting, Washington, D.C., April 1970.

ABSTRACT:

A systematic procedure for the design of polar icebreakers is given. To start the procedure and insure rational selection of ship size, powering and other features, a detailed list of owner requirements is necessary. Development of such requirements through the use of operations research methods is briefly discussed. The design procedure generally follows the traditional ship design spiral, but is modified where necessary for the design of icebreakers. Only those aspects of the design spiral peculiar to icebreakers are discussed in this paper. These include development of the hull form, calculation of icebreaking resistance, selection of the propulsion system, determination of hull scantlings, and investigation of beached stability. Wherever possible, analytical methods are presented. To accelerate the convergence of the design procedure and to assist the owner in matching his requirements to the resources he is prepared to expend, use of a computerized approximation of the design procedure is recommended. Some results concerning least-cost icebreaker proportions and the effects of key owner requirements on size, power and cost, obtained from one computerized version of the procedure, are included. Sufficient information for developing a similar approximation of the procedure is presented throughout the paper.

REFERENCE: Mellor, 1980.

TITLE: Ship resistance in thick brash ice.

AUTHOR: Mellor, M.

SOURCE: Cold Regions Science and Technology, Vol. 3, pp. 305-321,
February 1980.

ABSTRACT:

The mechanical properties of thick brash ice are considered, with special emphasis on the friction angle or for a linear Mohr-Coulomb failure criterion. The static equilibrium of a uniform brash layer is discussed, and the internal stresses are given for neutral, active, and passive stress states. Horizontal displacement of brash by a smooth vertical plate is analyzed, and the crushing forces for plastic yielding in the passive stress state are deduced for cohesionless brash and for ice that has finite internal cohesion. Propagation of a crushing disturbance is treated, and the condition for localization of crushing is derived from consideration of mass and momentum conservation. Formation of pressure ridges by localized crushing against a plate is analyzed, and estimates are obtained for the limiting thickness of ice crushed against a plate. Horizontal thrusting of brash by a plate inclined from the vertical is dealt with and it is argued that for large displacements the crushing forces against an inclined plate are the same as those for a vertical plate because of pressure ridge formation.

In the analysis of low speed ship resistance, the emphasis is on resistance at the bow. Starting from analysis of penetration by a slender smooth wedge and taking account of interface friction in an approximate way, an expression is obtained for the resistance of "sharp" conventional bows. Formation of a "flase nose" of brash in front of a blunt bow is considered for Mohr-Coulomb and Von Mises failure criteria, and an expression for the resistance of blunt bows is derived. Frictional resistance aft of the bow section is controlled largely by the normal pressure of ice against the hull. Bow resistance and hull friction can be combined into a single expression of the form ABR, where A is a dimensionless function, B is the ship's width and R is the passive state crushing force (per unit width) for the brash layer. The limiting ice resistance for ship movement can be related to the ship's thrust. For ships of a given type, which tend to have shaft power proportional to the cube of the beam, the limiting ice thickness is directly proportional to the beam. Using the very limited data on mechanical properties of brash ice and assuming that the propellers continue to function well, the estimates indicate that a Great Lakes bulk carrier would be near its limit of movement when the brash thickness in a wide channel is about 10% of the beam, while an icebreaker in salt water brash could perhaps keep moving until the brash thickness reached about 20% of the ship's beam.

REFERENCE: Melville Shipping Ltd., 1985.

TITLE: Redesign of the M.V. ARCTIC bow - additional model
tests at HSVA and WARC.

AUTHOR: Baker, D.N.

SOURCE: Transport Canada Publication TP5812E, May 1985.

ABSTRACT:

The report presents an analysis of the testing techniques used in three model ice basins: ACL, HSVA and WARC. The analysis of the testing techniques includes a review of the different ice types and a description of ice growing procedures at each tank. The data collection methods and equipment are discussed and comparisons of results are made between tanks and with available full scale data.

REFERENCE: Milano, 1975.

TITLE: Ship resistance to continuous motion in mush ice.

AUTHOR: Milano, V.

SOURCE: Proceedings, SNAME Ice Tech Symposium, Montreal, April 1975.

ABSTRACT:

An analytical solution to ship resistance in mush ice was the objective. Mush ice is defined as "heavy rafted brash ice" that has been broken by ship passages, wind and current. The surface may refreeze to certain depths and form a quasi-solid ice sheet.

The analysis follows the model developed by Milano for solid ice but is modified since climbing motion of the ship does not occur and the breaking pattern is different. Resistance is broken into three components: motion through broken ice, submergence forces and friction force. These forces are compared to the total ship energy lost due to impact with the ice. The resistance to motion through broken ice contains only inertial terms. Submergence forces include upending and forcing under of broken ice pieces. The friction force is computed by approximating the flow of ice around the hull as potential flow. The two cases of ship motion, continuous and ramming are considered.

The breaking pattern in mush ice is described as similar to that in solid ice: the ice breaks in cusps although the size is quite small and independent of ice thickness.

A computer program is used to calculate the resistance. A large number of ship parameters, including metacentric height and ship horsepower, are required for input data. The predicted resistance is compared to full scale data from the USCG MACKINAW.

An analytical description of ship resistance in mush ice is given.

REFERENCE: Milano, 1973.

TITLE: Ship resistance to continuous motion in ice.

AUTHOR: Milano, V.

SOURCE: Proceedings, SNAME Annual Meeting, New York, November 1973 (Paper evolved from Ph.D. Dissertation, Stevens Institute of Technology, N.S. 1972), Nov. 1973.

ABSTRACT:

Icebreaking is described in the range where total resistance to motion equals average thrust so that there is continuous progress at a constant average speed. The total resistance is the sum of several component resistances. Failure pattern used during the analysis is described as four major wedges at the bow mated to a succession of side cusp wedges.

Nevel's analysis of characteristic cusp and wedge length is used to determine the ice failure loads when the ship climbs onto the ice.

The motion of the ship through broken ice is examined and a formula for ship energy lost to kinetic energy imparted to the water, kinetic energy imparted to the ice and open water frictional resistance, is derived.

The energy lost by ship in crushing ice at impact points is obtained for two different cases: thick and thin ice.

The energy lost through friction and ice strain energy as the ship rides up onto the ice is computed by calculating the vertical and horizontal distance the ship rides up.

The turning resistance of the ice floes is found by equating the total inertial energy lost as the ship falls to the total rotational energy expended by the ship plus the rotational energy imparted to the ice pieces.

The last force examined is the sum of the buoyant forces as ice pieces are submerged plus the friction or energy.

The sum of the five resistance components is computed numerically. The resulting curve of resistance versus speed is not smooth but contains a knuckle. This is explained as a transition in ice failure mechanisms. The results are compared to test data.

The output is a totally analytical form for the icebreaking resistance of a ship.

REFERENCE: Naegle, 1980.

TITLE: Ice resistance and motion simulation for ships operating in the continuous mode of icebreaking.

AUTHOR: Naegle, J.

SOURCE: Ph.D. Thesis, University of Michigan, 1980.

ABSTRACT:

The objective was to develop a prediction method to incorporate the effects of hull form on icebreaking in the continuous mode. It is approached as a mechanics problem.

Equations of motion of the icebreaker for surge, pitch, heave and forward translation and equations of forces acting on the ship are solved numerically in a computer program to determine the resistance for a given ship of given velocity and ice thickness.

Forces acting on the ship are divided into non ice related (hydrodynamic, restoring, viscous and propulsion forces) and ice related (breaking, turning, submersion amd mechanical friction forces). The cusp breaking pattern is used to find equations for floe size. Formulas for the components of ice resistance are derived from previous theories, analysis, and fit with experimental data. Ventilation of the floes is accounted for in the turning forces and mechanical friction is included as part of the submergence forces.

The results of the computer program are discussed and compared to full scale and model data especially the data tabulated by Lewis et al (1976) and Vance (1974). Resistance is plotted as a function of speed. The total resistance and its components are examined to determine the influence of the parameters. This is also done for surge, pitch and heave of the ship. A sensitivity analysis is conducted and the most important assumptions are found to be those of floe size and ventilation.

A computer program which numerically solves the equations of motion of the icebreaker and predicts the total resistance of a given ship at a given speed and ice thickness has been derived. Ice resistance forces are derived semi-analytically.

REFERENCE: Narita, 1981.

TITLE: Some experimental study on hull forms for the new Japanese Antarctic research ship.

AUTHOR: Narita, S., Yamaguchi, M.

SOURCE: SNAME Star Symposium, June 1981.

ABSTRACT:

To reinforce and further promote various scientific exploratory activities in Antarctica and its surrounding waters, the Japanese Government has decided to build a new icebreaking research vessel - a triple-screw polar icebreaker with 30,000 shaft horsepower - which is nearly twice as big as the FUJI.

The hull form of the new vessel has been developed with the aid of modern ship-model testing so as to achieve powerful icebreaking capability as well as favourable cruising performance.

In this paper, the results of various model studies undertaken in the development program are extensively reported, and discussions and evaluation of these results are made in relation to the design feature of the hull forms, as well as in light of state-of-the-art ice-modelling technology.

The predicted full-scale icebreaking capability of the new vessel based on the model test results is compared with those calculated from some existing prediction methods and the full-scale data of the FUJI.

The results of model tests in ice-free water are also given, which included resistance and propulsion tests at normal cruising conditions, and overload tests at a very low speed range.

REFERENCE: Noble, 1981.

TITLE: Icebreaker bow forms - a parametric variation.

AUTHOR: Noble, P.

SOURCE: SNAME Star Symposium, 1981.

ABSTRACT:

Minimizing the resistance of icebreaking ships can allow the achievement of two goals. On the one hand, it can lead to ships which can handle existing icebreaking missions with reduced power and fuel requirements, or it can allow ships of specified power to carry out missions in more extreme ice conditions. From either point of view, the pressure to develop Arctic resources and the ever rising cost of fuel emphasizes the need to study means to minimize ice resistance.

This paper describes a model scale experimental project in which a parent hull and three variants were tested, and the results analyzed and correlated with the hull shape variables, bow section flare angles, and water plane angles.

The results of the program were firstly that two of the four variants showed significantly reduced resistance over the parent; and secondly it was shown that it is possible to correlate this reduced resistance to bow shape parameters.

REFERENCE: Nawwar, 1984.

TITLE: On the optimization of ship motions in heavy ice conditions.

AUTHOR: Nawwar, A.

SOURCE: Proceedings, 3rd OMAE Symposium, Paper No. 61, New Orleans, February 1984. Also published in ASME Transactions, Journal of Energy Resources Technology, June 1984.

ABSTRACT:

This paper presents an analytical closed form model for the analysis of ship performance in the ramming mode. The transition speed concept is used to provide a cut-off point for continuous mode icebreaking and switch to ramming. Exact solutions have been obtained for the differential equations of motion, thus making it possible to determine the penetration and time for any given part of the ramming cycle. Analysis of the ramming cycle and a typical example for application of the algorithms on an idealized ship (similar to the CCGS LOUIS S. ST. LAURENT) indicated that optimum conditions for ramming exist. Under these conditions the maximum speed of advance is realized. The optimum conditions do not necessarily require backing a long distance to achieve higher impact speeds.

REFERENCE: Pierce, 1978.

TITLE: Arctic marine technology: a review of ship resistance in ice.

AUTHOR: Pierce, T.

SOURCE: RINA Meeting, London, October 1978.

ABSTRACT:

The paper presented an overview of Arctic marine technology including ice capable ships and platofmrs, ice transiting performance, maneuverability in ice, structural integrity, propulsion system performance, ice hazard detection, etc. The author also reviewed level ice breaking equations and proposed a simplified approach to ridge resistance and penetration. he suggested that the minimum approach speed, V_i, in field ice of uniform thickness h in order to breack a significant ridge may be estimated from:

$$V_i^2 = K_0 \left[\frac{K_1 h^2 + K_2 h^3}{K_3 + K_4 h} \right]$$

where: $K_0 = B/1$

$K_1 = C_1 \sigma S K' K''$

$K_2 = C_2 \rho g m^2 K' K''^2$

$K_3 = \Delta / 2gl$

$K^4 = C_3 \rho B$

B = ship beam

l = resistance length

C_1, C_2, C_3 = icebreaking resistance coefficients

σ = flexural strength of ice

S = strength factor of ridge = adhesion x (1 - porosity)

K' = ratio of ice thickness to effective ridge width

K'' = ratio of ice thickness to effective ridge width

ρ = strength factor of ridge = adhesion x (1 - porosity)

g = gravity

m = density factor of ridge = 1 - porosity

Δ = ship displacement

The proposed formulation have not been tested or verified by field or model test data.

REFERENCE: Pozynak, 1981.

TITLE: The division of icebreaker resistance into components.

AUTHOR: Poznyak, I., Ionov, B.

SOURCE: SNAME Spring Meeting, STAR Symposium, Ottawa, June 1981.

ABSTRACT:

The resistance of an icebreaker in the continuous mode is expressed as the sum of four components including elastic icebreaking forces, friction forces, submergence forces, and velocity associated forces. The following formula have been proposed.

$$R = 0.004\sigma_f h^2[\alpha_1(\beta)B + f_d\alpha_2(\beta)L]$$

$$+ 0.1\gamma_0 hBL\left(\frac{tg\alpha_0}{tg\alpha_0 + B/L}\right)[\alpha_1(\beta)\sin\alpha_0 + f_d\alpha_2(\beta)(1 + \cos\alpha_0)]$$

$$+ 1.5\gamma_{ice} hB^2 Fr\left(1 + \frac{1}{\cos\alpha_0}\right)\left[\frac{(tg\alpha_0)^2}{(2\,tg\alpha_0 - B/L)} + f_d\right],$$

where L = length of the icebreaker on the waterline, m

B = breadth at midships, m

h = ice thickness, m

α_0 = the angle of entrance of the waterline, degrees

σ_f = ice flexural strength, Pa

γ_{ice} = specific gravity of ice, N/m^3

γ_0 = difference between the specific gravities of water and ice, N/m^3

f_d = dynamic coefficient of friction between the hull and the ice

and F_n = Froude number

$\alpha_1(\beta)$ and $\alpha_2(\beta)$ are non-dimensional coefficients of hull shape which may derived from the following equations:

$$\alpha_1(\beta) = \frac{1}{n}\sum_{i=0}^{n}\frac{0.57}{\sin\beta}(1,6\cos\beta + 0,11)$$

$$\alpha_2(\beta) = \frac{1}{n}\sum_{i=0}^{n}\frac{1}{\sin\beta}$$

A dimensional inconsistency in the first term of the equation should be brought to the attention of the users of this formula.

REFERENCE: Schwarz, 1985.

TITLE: Some latest developments in icebreaker technology.

AUTHOR: Schwarz, J.

SOURCE: 4th International Offshore Mechanics and Arctic Engineering Symposium, 1985.

ABSTRACT:

Icebreaking technology has been improved over the last 10 - 15 years so that the installed power of icebreaking ships could be drastically reduced. The improvement is demonstrated on four examples of icebreaking ships, one conventional and three advanced concepts, which have shown their icebreaking ability already in full scale.

The icebreaking capability of ships is suggested to be evaluated through model tests, theoretical approach and by full scale measurements. The evaluation should be carried out for various ice conditions by resistance and self propulsion tests.

Finally some thoughts are presented, on features of an advanced icebreaker.

REFERENCE: Schwarz, 1982.

TITLE: Icebreaking performance of the German polar research vessel.

AUTHOR: Schwarz, J.

SOURCE: Intermaritec '82 International Conference on Marine Research and Ocean Engineering, 1982.

ABSTRACT:

In order to fulfill the requirements for becoming a full member of the Antarctic Treaty Countries the Government of the Federal Republic of Germany has decided to build a polar research vessel. This ship will be used for research purposes in ice covered waters as well as for the supply of the German Antarctic Station (Filchner-Station). The hull form of the research vessel has been designed by the Hamburg Ship Model Basin. This report covers ice-technological aspects of the ship and reports on model test results in ice. The most important achievement was the development of ship lines which prevent the ingestion of ice into the propellers. Hereby propeller damage is avoided and the propeller efficiency is increased. The extrapolation of the model test results to full scale predicts that the polar research vessel will be able to break 1.0 m thick level ice at 5.2 knots.

REFERENCE: Takekuma, 1984.

TITLE: Arctic tanker bow forms and evaluation of full scale propulsive performance in ice.

AUTHOR: Takekuma, K., Kawaguchi, N., Glen, I.F.

SOURCE: SNAME Arctic Section, May 1984.

ABSTRACT:

With the progress of Arctic exploration, year-round transportation of products has been extensively investigated. Ice-going tankers or LNG carriers are considered to be promising transportation candidates. In this paper, the influence of propulsion plant output on the conceptual design are discussed. The importance of accurate prediction of full scale propulsive performance and optimization of the hull form for minimum ice resistance are noted. The paper examines aspects of model-ship correlation for estimating the propulsion power for a large ice-going ship, the effect of bow form on performance in ice as determined from model tests in ice and performs a statistical analysis based on recent knowledge of the icebreaking phenomena and accumulated full scale data of currently operating ice-going ships.

REFERENCE: Tatinclaux, 1984.

TITLE: Model tests in ice of a Canadian Coast Guard R-Class icebreaker.

AUTHOR: Tatinclaux, J.

SOURCE: CRREL Special Report 84-6, April 1984.

ABSTRACT:

This report represents the results of resistance and propulsion tests in level ice of a 1:20 scale model of the R-Class icebreaker of the Canadian Coast Guard. On the basis of the model test results, full-scale performance is predicted and compared with available full-scale trials data.

A non-linear regression analysis of the model data yielded a prediction equation and 0.966 correlation of other published formulas for ice resistance. Carter's formula had the best agreement with the data especially as it is assumed that E = 5000 as Carter proposes. Predicted ice resistance and required propeller rpm, thrust and delivered power are lower than full scale measurements. This disagreement was attributed to the fact that the ship model had a much lower ice friction coefficient than the prototype. On the other hand, predictions of thrust and power for a given ship speed and propeller rpm are in good agreement with corresponding full scale measurements.

REFERENCE: Vance, 1981.

TITLE: Full scale icebreaking test of the USCGC KATMAI BAY.

AUTHOR: Vance, G., Goodwin, J., Gracewski, A.

SOURCE: SNAME Star Symposium, 1981.

ABSTRACT:

This paper presents the results of tests on the new U.S. Coast Guard 42.7 m (140 foot) icebreaking tug KATMAI BAY (WTGB-101). Tests were performed on Whitefish Bay in Lake Superior and on the St. Marys River. Results indicate the icebreaking tug can continuously penetrate up to 55.9 cm (22 in.) of level fresh ice with 5.1 - 7.6 cm (203 in) of snow cover. It can also proceed continuously in up to 121.9 cm (48 in) of brash ice. By backing and ramming, up to 76.2 cm (30 in) of plate ice was broken. The installed bubbler system demonstrated it could decrease the required shaft horsepower of the cutter up to 25-35% in level ice and up to 30-50% in brash ice depending on ice conditions. The low friction coating appeared effective in decreasing the friction factor when it remained intact. When it peeled off, it appeared to make conditions worse than ordinary hull paint.

REFERENCE: Vance, 1980.

TITLE: Full scale evaluation of the air bubbler system on the Great Lakes icebreaker USCGC KATMAI BAY.

AUTHOR: Vance, G.P.

SOURCE: Intermaritec '80 Int. Conference on Marine Research and Ocean Engineering, 1980.

ABSTRACT:

This paper presents the results of the tests conducted on the U.S. Coast Guard's 42.6 m Great Lakes Icebreaker KATMAI BAY. The KATMAI BAY is the first of a class of icebreaking tugs specifically designed for icebreaking on lakes and rivers. It displaces 700 tons and has a single propeller driven by a 2500 HP D.C. motor. It has an air bubbler system and low friction bottom coating of Inertia 160, to reduce the coefficient of friction between the ice and the ship's hull. the vessel was tested in homogeneous level ice and in brash ice with and without the bubbler system in operation. Results indicate that the bubbler system decreases the required power by about 30% and was particularly effective in improving the propulsive coefficient while operating in brash ice.

REFERENCE: Vance, 1980 .

TITLE: Analysis of the performance of a 140 foot Great Lakes icebreaker, USCGC KATMAI BAY.

AUTHOR: Vance, G.

SOURCE: CRREL Report 80-8, February 1980.

ABSTRACT:

Maximum ice and snow operational capabilities of USCG 140 ft. icebreaker KATMAI BAY were analyzed and the effectiveness of the bubbler system were tested.

Performance in level and brash ice is presented as well as performance with and without the bubbler system. The results are presented as plots of shaft horsepower versus speed. Use of the bubbler system reduced the required power by 25 to 35% in level ice and 30 - 50% in brash ice. The bubbler system contributed very little in the ramming mode. The bubbler system can develop a reverse thrust sufficient to propel the model rearward at 1 knot in open water but then it reduces the propulsive coefficient in brash ice.

The low friction coating was effective in decreasing the friction factor when intact but when it peels off the results are worse than plain paint. An average dynamic friction factor of 0.15 could be used over the entire hull for these tests.

A regression analysis of the data was performed using the resistance equation developed previously by the author in level ice.

$$R = 55.8583\rho_{\Delta}gBh^{2} + 0.0188\ \sigma g^{-0.5}h^{0.5}B$$

A similar equation was found for operation in level ice with the bubbler system.

For brash ice the equation had the form:

$$R = -C_{1}\rho_{\Delta}gBh^{2} + C_{2}\rho_{i}V^{2}LB^{0.35}h^{0.65}$$

with the coefficients varying with thickness and use of bubbler system.

The thickness of level and brash ice in which the ship can operate continuously and some information on ramming was obtained. The bubbler efficiency was also determined for various operating conditions. Formulas for resistance prediction were derived from the test data.

REFERENCE: Vance, 1979.

TITLE: A summary review of analytical ice resistance prediction techniques.

AUTHOR: Vance, G.

SOURCE: CRREL Technical Note, September 1979.

ABSTRACT:

This note, prepared for the 15th Meeting of the ITTC, presented a non-technical review of all the then known analytical methods of predicting the performance of vessels in ice. The author identified the following relevant models:

1. Level Homogeneous Ice:	Kashteljan, V.I.	1968
	Milano, V.R.	1973
	Dorgeloh, H.	1978
	Arctec/Mitsui	1979
2. Broken or Brash Ice:	Kashteljan, V.I.	1968
	Milano, V.R.	1975
	J.J. McMullen Assoc.	1979
	Arctec/Mitsui	1979
3. Pressure Ridge Algorithm:	Arctec	1977
	J.J. McMullen Assoc.	1979
	Keinonen, A.	1979

REFERENCE: Vance, 1975.

TITLE: A scaling system for vessels modelled in ice.

AUTHOR: Vance, G.P.

SOURCE: SNAME Ice Tech Symposium, Montreal, April 1975.

ABSTRACT:

The modelling techniques and law of similitude for modelling in ice are discussed. Relationships to satisfy geometric kinematic and dynamic similarity are developed. Reynold's scaling is ignored since viscous effects are small. Analytical and semi-analytical resistance theories, especially those of Milano and Enkvist, are used to determine the important parameters in the process. By examining the icebreaking process, the parameters are grouped into a non dimensional form. A regression analysis on model and full scale data from five ships determined the best form of the resistance equation:

$$R_{ice} = C_S \rho_\Delta g B h^2 + C_B \sigma B h + C_V \rho_i V^2 L h^{.65} B^{.35}$$

The coefficients C_S, C_B and C_V are determined for each ship from properly scaled model test data. The results indicate that full scale resistance can be predicted to within 10% of measured prototype values. The technique is applicable to homogeneous ice sheets under neutral pressure conditions. The effects of the coefficient of friction is also taken into account.

An equation for R_{ice} whose coefficients are determined from properly scaled test data hss resulted. The resulting equation can then be used to predict the full scale resistance in level ice for that particular ship.

REFERENCE: Voelker, 1977.

TITLE: Operational capability of a polar research ship.

AUTHOR: Voelker, R.

SOURCE: POAC, 1977.

ABSTRACT:

Based on the projected developments in the Arctic regions and the corresponding lack of adequate oceanographic data in this area, the need for a research ship capable of operating in ice-covered waters has recently been established. The performance requirements for a research ship which would fulfill these needs includes the capability for breaking up to 0.46 m of level ice at a speed of 3 knots. As ice conditions in the polar regions vary as a function of time, it was decided to determine the operational limits of the ship for different geographic areas as a function of calendar month. This paper presents the results of that operational study for Arctic East, Arctic West, and Antarctica.

REFERENCE: Wartsila, 1972.

TITLE: Great Lakes ore carrier series ice resistance model test program.

AUTHOR: Johansson, B., Makinen, E.

SOURCE: WIMB Test Report No. 18 for Maritime Administration, U.S. Dept. of Commerce, December 1972.

ABSTRACT:

Icebreaking resistance in level and broken ice for the range of hull shapes and lengths of ore carriers operating in the Great Lakes was studied. Model tests in level and broken ice were conducted using 11 different models representing a wide range of hull forms. Full scale tests in level ice were conducted with three ships. Calibration coefficients were used to correlate the model data to the full scale data. To fit the data any mathematical function was used so the formulas are not derived from any physical phenomena and therefore extrapolation outside the parameter set is dangerous. Predictions for resistance in broken channels have a lower reliability since full scale trials were not performed.

The original formula (from report No. 18) was reviewed and found inadequate for ships longer than 715 feet. A revised formula based on the original data for ships up to 1000 feet long was found. The influence of draft was not included but according to theories presented in this report, its influence is small.

For level ice within the range of L/B, h, V and bow angles ( ) given:

$$R_{ice} = Bh^2 \ g \ C \ (C_S + C_V)$$

where C , C_S and C_V are coefficients determined by equation from ice thickness, velocity and ship parameters.

An empirical equation which can be used to predict ice resistance of ships provided ship and ice characteristics within the ranges given has been derived.

REFERENCE: Wartsila, 1973.

TITLE: Ice Resistance in level ice of ships with main dimensions typical for the Great Lakes bulk carriers.

AUTHOR: Makinen, E., Roos, A.M.

SOURCE: Supplement to WIMB Test Report No. A18, September 1973.

ABSTRACT:

Icebreaking resistance in level and broken ice for the range of hull shapes and lengths of ore carriers operating in the Great Lakes was studied. Model tests in level and broken ice were conducted using 11 different models representing a wide range of hull forms. Full scale tests in level ice were conducted with three ships. Calibration coefficients were used to correlate the model data to the full scale data. To fit the data any mathematical function was used so the formulas are not derived from any physical phenomena and therefore extrapolation outside the parameter set is dangerous. Predictions for resistance in broken channels have a lower reliability since full scale trials were not performed.

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An empirical equation which can be used to predict ice resistance of ships provided ship and ice characteristics within the ranges given has been derived.

2.4.3 Propulsion

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An examination of possible future marine propulsion systems. A study for Melville Shipping Ltd. 1979.

REFERENCE: Andersson, 1983.

TITLE: CPP in ice.

AUTHOR: Andersson, S.O.

SOURCE: West European Graduate Education Marine Technology.

ABSTRACT:

The controllable pitch propeller has traditionally been used for various kinds of ice-going vessels. Today's knowledge and technique in the field of ice-going propellers give guarantee for the reliable function of the CP propellers also in heavy ice.

Knowledge of magnitude and direction of the forces acting on a propeller blade when hitting ice is limited due to the complex nature of the problem and the difficulties in making accurate models or full scale measurements. Today, propeller-blades and shafts for ice-going ships are dimensioned according to the ice class rules, while the selection of the hub is still a part of the fascinating art of propeller design. The main difficulties in this work are to gain an understanding of the ice loads for an actual propeller and to generalize this knowledge into methods of strength calculation.

REFERENCE: Appleton, 1978.

TITLE: A place for superconducting DC machines in marine propulsion.

AUTHOR: Appleton, A.D.; Bartram, T.C.

SOURCE: IPC Business Press, 1978.

ABSTRACT:

Superconducting d.c. machines have been under development for a number of years and it has become apparent that marine propulsion is an application where these machines may show a great advantage. This paper discusses the special features of the motors which allow them to achieve a performance which is beyond that of any other electrical machine. Special reference is made to icebreakers including a discussion on the power and control systems.

The paper indicates a commentary on progress in this field and suggests the likely trends for the future.

Paper relates the superconducting d.c. motors to the icebreaking ship application. While the paper deals with the application of the superconducting motors, no such motors of the size proposed has yet been built.

REFERENCE: De George 1982

TITLE: Combined effect of vertical and horizontal lineshaft alignment on main reduction gear

AUTHOR: De George, V.A.

SOURCE: Marine Technology, Vol. 19, No. 2, April 1982.

ABSTRACT:

Vertical lineshaft alignment has received a great deal of attention from the marine industry without a proper understanding of the reasons for it. Horizontal lineshaft alignment, however, has not been considered as important and in many cases has been completely neglected. This paper shows the relationship between lineshaft alignment and main reduction gear-pinion tooth loads. It is hoped that the reader can put in perspective the significance of this relationship.

Very useful paper which is extremely relevant to large gears in arctic class ships.

REFERENCE: Dick, 1980.

TITLE: Propulsion system selection for Arctic liquid natural gas carriers.

AUTHOR: Dick, R.A.; Wainwright, J.G.

SOURCE: Presented to SNAME Eastern Canadian Section, April 15, 1980.

ABSTRACT:

Natural gas was discovered in the Canadian Arctic Islands in 1970 when Panarctic Oils Ltd. experienced a successful well at Drake Point on Melville Island. This discovery and the subsequent crude oil find in the Prudhoe Bay area of Alaska spawned considerable Arctic Islands exploration so that by mid-1979, Canada's National Energy Board had estimated established reserves in the Arctic Islands to be 9.2 trillion cubic feet. These reserves are not considered sufficient to justify economically a gas pipeline connecting the Arctic Islands to the markets to the south, but the reserves are sufficient to support a project which entails liquifying the natural gas in the Arctic and then transporting the energy to market by icebreaking carriers.

REFERENCE: Edwards, 1976.

TITLE: Methods for predicting force encountered by propellers during interaction with ice.

AUTHOR: Edwards, R.Y.

SOURCE: 3rd LIPS Propeller Symposium, 1976.

ABSTRACT:

The propellers of ships operating in ice covered waters encounter fragments of ice and are frequently damaged. The interactions between a propeller and an ice fragment may be divided into two categories: impact and ice cutting or milling. The former occurs when the mass of the ice fragment is sufficiently low for the period of encounter to be very short, the frament ultimately being deflected by the propeller blade. This category of ice encounter has been studied by Grim and Schenzle. The level of stress produced rarely is sufficient to cause damage to modern propellers strengthened for icebreaking service.

REFERENCE: Fagerjord, O.

TITLE: Improving the efficiency of propulsion machinery.

AUTHOR: Fagerjord, O., Rein, H.

SOURCE: Institute of Marine Engineering, Vol. 94, Paper C104, 1982.

ABSTRACT:

Many ships are operating at reduced speed and are, at the same time, frequently experiencing a significant drop in machinery efficiency relative to design speed conditions. The authors discuss methods of saving fuel in existing ships by derating, modifying and tuning the propulsion machinery. Emphasis is placed on arriving at design solutions which represent optima when due account is taken of the characteristics of both the machinery and the propeller. The effect on overall fuel consumption of different systems for generating the required electric power in diesel ships is briefly discussed.

Paper usefully discusses factors which influence the efficiency of steam turbine systems and compares the operating costs between different steam cycles.

REFERENCE: Finizio, 1974.

TITLE: USCG POLAR STAR - Combination of a diesel electric propulsion plant with a geared gas turbine booster plant.

AUTHOR: Finizio, A.F.

SOURCE: ASME Publications, April 1978.

ABSTRACT:

This paper is a progress report on the selection and design of equipment for the USCG POLAR icebreaker. A discussion of equipment concepts, design, and modifications to off-the-shelf equipment is presented with a review of major design problem areas and solutions. The various modes of operation of the combined system with the attended degrees of flexibility and limitations of each are also defined.

Highly descriptive of an icebreaker COGODE system. Lacking in technical detail.

REFERENCE: Greene, 1982.

TITLE: Technology development for electric ship propulsion.

AUTHOR: Greene, D., Powell, R., Gripp, L.

SOURCE: IEEE Transcripts on Industrial Applications, Vol. 1A-18, No. 3, May/June 1982.

ABSTRACT:

An overview of the current and projected state of the art for marine electric drive systems is presented, together with an assessment of relative development risk. The objectives for pursuing development of electric drive are arrangement flexibility, controlability, variable reduction ratio, reliability, and provision of ship's service power from the main bus. Several new technologies permit achievement of these objectives without weight, cost, and efficiency penalties. Four technology areas show promise of significantly increasing electric drive power density, including forced gas cooling, direct water cooling, permanent magnet exitation, and superconducting electromagnet excitation. Each of these technologies is examined to display the essential machine characteristics, the areas of technical risk, and the degree of anticipated weight and volume reduction for a typical application. System considerations for propulsion systems utilizing the various types of machine technologies are also discussed.

One of the best papers on present status of marine electric propulsion.

REFERENCE: Hill, 1980.

TITLE: Some considerations into the design of sterntube bearings.

AUTHOR: Hill, A.; Martin, F.A.

SOURCE: Transcripts, Marine Engineer, Paper C 39, Vol. 91,
Conference No. 4.

ABSTRACT:

The behaviour and performance of stern tube bearings and seals are to some extent interdependent; both must operate under conditions imposed upon them by the propeller, shafting and hull system, determined partly during the construction of the ship but subsequently changed according to the loading of the ship, the speed, sea and climatic conditions. The paper sets out, briefly, some of the failure statistics which confirm that this is one of the less reliable parts of the ship at the present time. Although somewhat interdependent, it is, however, convenient to consider bearings and seals separately. The criteria for safe operation of the bearing are stated. The effects of clearance, length/diameter ratio, bore configuration, alignment and shaft bending upon oil film thickness, stiffness and damping capacity, are discussed with examples. Some possible palliatives are described. The behaviour of seals is considered, and in particular the effects of pressure and vibration are discussed. Different arrangements of lip seals are described, together with service experience, leading to the concept of complete separation of the water and oil systems.

Very useful paper which provides good information, both practical and theoretical of the behaviour of the tailshaft is its bearings, of large modern ships.

REFERENCE: Imamura, 1982.

TITLE: Design concept of strength for icebreaker shafting.

AUTHOR: Imamura, S.; Teramoto, K.

SOURCE:

ABSTRACT:

This paper otlined the design concept for the propeller and propeller shaft system of the icebreaker "SHIRASE".

A review of the propeller/shaft construction and material selection criteria was given, and based upon their study, keyed fitting, fixed pitch and stainless steel propellers were selected for "SHIRASE" for stern tube bearings, the sea-water lubricated type was chosen with lignumvitae as the bearing material and, a low-alloy steel propeller shaft was adopted in consideration of shaft transmission efficiency and weight.

The strength design method of the propeller and propeller shaft of IGNATJEV was discussed with the operational experience of "FUJI" and the finite-element stress analysis carried out in NKK. The comparison results showed that the IGNATJEV's calculation method using the Jagodkin's ice torque was an excellent general calculation method for designing propeller and propeller shafts of icebreakers.

On the 'SHIRASE" the resonance point of torsional vibrations was set between bollard rotation speed and continuous maximum rotation speed, while resonance points of lateral and axial vibrations were set above the continuous maximum rotation speed.

REFERENCE: Jagodkin, 1963.

TITLE: Analtyic determination of the resistance moment of a propeller during its interaction with ice.

AUTHOR: Jagodkin, V.

SOURCE: Problemy Arktiki I Antarktiki 13, 1963.

ABSTRACT:

This is a very detailed account of the title topic. Main attention is paid to interacting with very large floes which must be milled by the propeller. This action produces maximum loads on the propeller.

The analytical model, described in the paper, determined the maximum force and moment opposing the rotation of the propeller. The load was related to the ice characteristics, propeller parameters, and the speed of the ship and propeller.

The results were compared in detail with actual measurements which were performed on icebreaker KAPITAN VORONIN in ice.

In spite of its simplicity, the model is still commonly used today for shaft torque evaluation. The model however is incapable of determining the blade spindle moment under ice loads which is important to CP propeller designs.

REFERENCE: Juurmaa, 1981.

TITLE: On propulsion and its efficiency in ice.

AUTHOR: Juurmaa, K.

SOURCE: SNAME Star Symposium, 1981.

ABSTRACT:

In this paper the factors to be considered when determinng the icebreaking capability of different ship-propeller configurations are discussed. Some results of model tests with propellers in different ice conditions are presented and also results of model tests with one icebreaker with nozzled propellers, conventional propellers and without any propellers at all, i.e. pure towing resistance, are discussed. The propeller ice interaction in model scale is compared to full-scale measurements.

REFERENCE: Kotras, 1985.

TITLE: Determination of propeller-ice milling loads.

AUTHOR: Kotras, T., Humphreys, D., Baird, A., Morris, G., Morley, G.

SOURCE: Department of Transportation, U.S. Coast Guard.

ABSTRACT:

In designing ice transitting ships, a major concern is the design of the propeller to provide adequate strength to resist ice loads due to propeller ice milling while still providing good propeller efficiency for open water operations as well as high icebreaking thrust at slow advance speeds. As a result, propeller design is a compromise between strength and efficiency. This is especially true for ice transitting ships that must transit long distances on ice free routes and then perform difficult icebreaking operations. The geometric properties of a propeller blade that provide good strength are blade width and thickness. Unfortunately, increasing these properties does not provide the best efficiency. Propeller design for ice transitting ships in general has tended to favour strength and reliability over efficiency in design compromises. The purpose of this paper is to outline a methodology for determining propeller ice milling loads as a function of propeller characteristics, propeller speed, ship speed, ice conditions and depth of ice milling to help in the propeller design process.

REFERENCE: Lewis, 1983.

TITLE: Propulsion coefficients and propellor design for icebreaking ships.

AUTHOR: Lewis, [illegible]

SOURCE: WEGEMT [illegible]

ABSTRACT:

At the heart of the ship design process is the problem of selecting power required and the propeller to deliver it. The problem is faced not only by ice-worthy ship designers; open water surface ship designers and submarine designers have dealt with the problem for decades. The data required to solve this design problem falls into three groups.

- Data on the resistance of the hull - for ice-worthy ships this includes not only water resistance, but also resistance in various ice conditions which are to be encountered along the trade route.
- Data on suitable propellers - normally, these are in the form of thrust and torque characteristics as a function of shaft speed, advance speed, pitch/diameter ratio, expanded area ratio, etc.
- Data on the interaction coefficients of these propellers with the ship's hull - in the case of ice-worthy ships this must include the effects of ice.

In the design of ice-worthy ships, large gaps exist in the available data necessary to solve this problem.

REFERENCE: Marine Engineer Review, 1985.

TITLE: Polymer alloy extends shaft bearing life.

AUTHOR: Marine Engineer Review

SOURCE: Marine Engineer Review, 1985.

ABSTRACT:

Due to repeated problems of high water of wear down of the stern tube bearings of the USCG icebreakers Polar Star and Polar Sea, staves made of an alloy of polymer and synthetic rubber were fitted to the sterntube bearing of the post shaft of the Polar Sea while laminated phenolic micarta staves were fitted to the starboard shaft bearing in 1980. One year later the wear down was measured and found to be nearly one tenth less on the shaft fitted with the polymer alloy bearing staves than the shaft with the original bearing material.

Polymer alloy material has also been used for rudder bearings with great success.

Useful material if water lubricated bearings are to be considered.

REFERENCE: Marine Engineer Review, 1986.

TITLE: Cyclo-converter propulsion for Russian icebreakers.

AUTHOR: Marine Engineer Review

SOURCE: Marine Engineer Review, July 1986.

ABSTRACT:

Two cyclo-converter propulsion systems have been ordered by the USSR for two nuclear powered icebreakers each fitted with three propellers. The ratings for each are 12 KV, 12 MW. The systems will be similar to those supplied to the Finnish Board of Navigation for the Karhen II class of icebreakers, but larger.

Short but informative article.

REFERENCE: McCann, 1973.

TITLE: Super-conducting electric propulsion systems for merchant and naval ship concepts.

AUTHOR: McCann, E., Mole, C.

SOURCE: SNAME, New York, November 1973.

ABSTRACT:

Electric ship propulsion systems have always offered flexibility of arrangement and design. The weight, volume, and cost effectiveness associated more often discouraged application, although a wide range of historical application exists for a comparison base. In 1911 scientists discovered the superconducting phenomenon, where certain conductors reached a state of zero electrical resistance near absolute zero. This phenomenon has led to development of a class of ship electric propulsion systems that offer significant reduction in weight and volume - by factors of 4 to 10 over conventional electric drives. This historical base is used to define potential systems using superconducting technology. Application studies to contemporary ships concepts are presented, as well as definition of typical system elements required.

Although an old paper, this provides a good review of electric systems and the potential of super conducting motors.

REFERENCE: McIlvean, 1976.

TITLE: Sterntube seals and plastic bearings - a shipowner's developments and experience.

AUTHOR: McIlvean

SOURCE: Institu [illegible] Marine Engineers, 1976.

ABSTRACT:

Modern elastometic lip type stern seals equipped with fluorinated rubber sealing rings offer an improvement in simplicity and reliability over the older type of seal which incorporated a "guide ring" system together with nitrile rubber sealing rings. The use of ceramic coatings for stern seal liners can be accepted to reduce the incidence of liner wear and corrosion. The introduction of an oil lubricated reinforced plastic sterntube bearing material, as an alternative to white metal, has given excellent results under arduous service conditions. It has been noted from test rig investigations that a reinforced plastic bearing will accommodate comparatively high values of shaft misalignment without ill effects. The combination of a modern lip type stern seal and reinforced plastic bearing represents a very simple bearing and seal system which offers a high degree of operational availability under extraordinary conditions.

Unique paper which describes the problems experienced by a ship owner with lip seals and has experience the early stages in the development of cresylic resen bearings.

REFERENCE: Melville Shipping Ltd., 1980.

TITLE: Computerized propeller-ice interaction model.

AUTHOR: Cheung, H.C.; Laskow, V.

SOURCE: Melville Shipping Ltd., 1980.

ABSTRACT:

A computerized propeller ice interaction model "PRICI" has been developed for determining the ice loads exerting upon propellers for various propeller operating and ice interaction conditions. The model considered the actions of ice crushing and shearing during the interaction, and the geometry of the blades was accurately represented by 3-dimensional finite elements. The effects of ice confinement and contact conditions and friction were incorporated.

The model was calibrated with the physical modelling results supplied by Kawasaki Heavy Industries, and shown to produce reliable ice load predictions when comparing with the full scale data of a number of icebreaking vessels.

REFERENCE: Melville Shipping Ltd., 1983.

TITLE: Technical evaluation of combined gas and steam turbine propulsion system for Canadian icebreaking duties.

AUTHOR: Thompson, E.W., Wainwright, J.G.

SOURCE: Transport Canada, Transport Development Centre TP4513E, 1983.

ABSTRACT:

A very high power propulsion system was required for two large CASPPR ice class 7 LNG carriers. A COGAS system based upon two or three aero-derivative gas turbines plus one steam turbine was evaluated for its feasibility to be used as a propulsion system. The steam for the steam turbine was to be raised using waste heat from the gas turbines. The study concluded the system was feasible and would provide good fuel economy even at pact load.

Although the study concluded the system was technically feasible the problem of later design and size and ducting the exhaust gases has not been addressed. Many problems of system design and control must be addressed as well as boiler and uptake corrosion when natural gas is is burnt. Boiler response to rapid load changes has not been well considered.

REFERENCE: Motor Ship, 1983.

TITLE: KALVIK/TERRY FOX, a poweful pair of Arctic Class 4 anchor handling/tug/supply ships.

AUTHOR: Motor Ship

SOURCE: Motor Ship, October 1983.

ABSTRACT:

Two of the most powerful icebreaking multi-purpose support vessels have recently entered service in the Beaufort Sea. The vessels have been built to CASPPR ice class 4 and are intended for operation from April to December in the Beaufort Sea.

The ships have been designed by German & Milne and have been built by Burrard Garrow Corp. in Victoria and Vancouver, B.C.

The ships are 88 m overall with a beam of 17.8 m and a draft of 8 m. The vessels are powered by 4 SWD TM410 diesel engines, combined output of 17.3 MW; which drive two controllable pitch propellers via Lohmamm & Stoltefoht Novtlus gearboxes. A 750 KW air bubbling system and a stern thruster are fitted.

Descriptive paper of the two ships with a diagram of the machinery layout showing the use of shaft flywheels.

REFERENCE: Mourelatos, 1985.

TITLE: Finite element analysis of elasto-hydrodynamic stern bearings.

AUTHOR: Mourelatos, Z.

SOURCE: SNAME Trans. Vol 90, 1985.

ABSTRACT:

A finite-element analysis is performed for a marine shafting/bearing system utilizing a hydrodynamic, oil-lubricated stern bearing. The stern bearing analysis consists of three-dimensional finite-element analyses of the shafting and the elastic bearing liner, a two-dimensional finite-element analysis of the oil film hydrodynamics, and iterative techniques to establish the equilibrium position between the shaft, the oil film and the bearing material. The shafting system analysis is formulated as a coupled three-dimensional problem using beam elements which include bending, shear, thrust, and possible continuous elastic foundation bearing support. The two-dimensional finite-element analysis of the oil film hydrodynamics is based on the Reynolds equation. The oil film domain is discretized into linear or quadratic triangular elements. The three-dimensional finite-element analysis of the bearing material is modeled by linear isoparametric rectangular prism elements. This bearing material analysis includes the capability to treat either (i) a conventional, metallic stern bearing or (ii) a highly elastic, anisotropic plastic bearing. A nonderivative optimization (minimization) technique is utilized to search systematically for the equilibrium position of the shaft in the bearing clearance. A convergent predictor-corrector process which takes full advantage of the physics of this particular problem is introduced within each objective function evaluation. The results of this analysis are in good agreement with a wide range of experimental data from a stern bearing simulation apparatus.

A very important paper with an excellent reference list. This work and its application to very large Arctic ships is essential if very large shaft power is to be installed.

REFERENCE: The Naval Architect, 1983.

TITLE: Gear up for ice.

AUTHOR: The Naval Architect

SOURCE: The Naval Architect, September 1983.

ABSTRACT:

The West German gear manufacturer RENK has recently completed the world's largest twin imput ice-class gear units, the highlight of a new trend in ice-class vessel propulsion using c.p. propellers and gear box linked diesel primemovers.

One of several articles in the technical press giving details of this large gear and other gears for ice class ships delivered by RENK, West Germany.

REFERENCE: Oehlers, 1983.

TITLE: Requirements and solutions for propulsion systems on vessels for Arctic conditions.

AUTHOR: Oehlers, W.

SOURCE: CSSRA Technical Conference, 1983.

ABSTRACT:

For icebreaking vessels MAN - B&W has developed different solutions for propulsion systems.

Special provisions must be made for the cooling water, air intake and fuel oil systems of the main propulsion four-stroke diesel engines.

For fixed pitch propeller systems a mechanical power transmission in combination with hydraulic torque converters was developed, for controllable pitch propeller units an energy storage system was engineered.

Paper provides outline of engine operating problems in low temperature and MAN - B&W opinions on how to overcome the problems. Information is useful but not unique.

REFERENCE: O'Hare, 1972.

TITLE: Operating experience with gas turbine conversion ships.

AUTHOR: O'Hare, T., Holburn, J.

SOURCE: Institute for Marine Engineers, London.

ABSTRACT:

The reason for selection of aircraft derivitive gas turbines and principal design features of the machinery installation for a class of four high speed container ships are presented. Subsequent operational experience, although at this point in time somewhat limited, is measured against initial expectations. The performance of auxiliary systems, maintenance requirements and the importance of fuel system cleanliness are discussed. Details of gas generator change outs, with particular emphasis on the problems posed by environmental conditions are presented, with the belief that this is the only real barrier to the realization of the full potential of this type of propulsion machinery.

Paper was written in 1972 and does not reflect in total the operational problems of the engines with respect to MBO and time between engine change outs. Later papers are available which describe events leading to the decision by the Owners to re-engine the vessel with mechanic speed diesel engines.

REFERENCE: Pinnekamp, 1974.

TITLE: Performance of marine reduction gears with modern design features.

AUTHOR: Pinnekamp, W.

SOURCE: Transcripts, Institute of Marine Engineering, November 1974.

ABSTRACT:

A new type of marine reduction gear for two or more medium speed diesel engines has been developed and was thus far applied to total ratings between 14 and 34 MW (20,000 and 46,000 hp). For these extreme ratings, modern design features have been introduced, which are: absolute symmetry of all essential structural elements, four point support, and cardan-shaft characteristics of input shafts. By these measures, certain problems were expected to be solved which have, from earlier experience, turned out to be of increasing significance with larger dimensions of ships and reduction gears. These problems are unequal load distribution over the face width and radial displacements of shafts. During trials, the performance of these modern gears was excellent. This was proved by special investigations, which confirmed that the above mentioned problems were indeed satisfactorily solved, and that marginal problems, which should always be anticipated with new equipment, did not appear.

Although the paper is now dated, the information is valid and still relevant. Of particular importance is the concept of the location of the gearbox support parts on the axes of symmetry to minimise the experience of hull girder deflection on gearing external alignment.

REFERENCE: Robertson, 1975.

TITLE: Engineering study on propellers.

AUTHOR: Robertson, G., Collier, J. Klosowski, S., Roper, J.E.

SOURCE: Canadian Coast Guard, 1975.

ABSTRACT:

This report described an engineering study on propellers for use in icebreaking ships with particular reference to CP and FP propeller systems comparisons. The study results were presented in three separated reports:

Report 1 - Existing Installations - The philosophy, design, construction, installation and operational experience of then existing propellers for icebreaking ships were reviewed and analysed. The report included a documentation of the propeller data and comments collected from five major CP propeller manufacturers, namely, Karlstads Mechaniska Werkstad, Escher Wyss, Lips B.V., Liaaen, and Stone Manganese Marine Limited.

Report 2 - Existing Designs - The various aspects of ice propeller design were discussed, including the CP propeller pitch control mechanism, propeller dimension, power, reliability, durability and effectiveness.

Report 3 - Future Designs - This report identified the manufacturers considered to be capable of producing CP propellers for high powered icebreakers. The author's opinions were given with respect to allowable stresses and loading, propeller performance, and the selection of propeller and prime mover systems.

REFERENCE: Saunders-Davies, 1980.

TITLE: Factors affecting the performance of tanker gearing - an operator's view.

AUTHOR: Saunders-Davies, D.

SOURCE: Transcripts, Institute for Marine Engineers, February 1980.

ABSTRACT:

The past thirty years have shown a rapid and simultaneous increase of the dimensions of ships and the outputs of their propulsion plants. During this period the deadweight tonnage of tankers has increased from 20.000 tdw to 553.000 tdw, the powers of turbine and gearing driven propulsion plants from 8.000 to 60.000 SHP

This has resulted in an incompatibility between the flexibility of the hull steel-work and the stiffness of the line shaftings. Hull steel work deformations due to loading conditions and sea state, exceeding in a large extent the gearing machining and mounting tolerances, have acted in detrimental way on the behaviour of marine gearings. Severe damages of gearing teeth have occured.

One of the few papers which have recorded some of the more typical problems encountered with large soft gears. The paper deals principally with turbine gear fitted to ULCCS.

REFERENCE: Sasaki, 1979.

TITLE: Ice navigation and shafting strength of icebreaker FUJI.

AUTHOR: Sasaki, H., Yabuki, S., Sato, M.

SOURCE: Journal of MESJ, Vol. 7, No. 1, pp. 87-89, March 1979.

ABSTRACT:

Icebreaker FUJI has been working for the support of Antarctic research expedition since her completion in 1965. There were propeller-blade damages two times due to heavy ice condition during 13 years operation.

On the 18th research (1976-1977), two engineers (Authors) were permitted to go on board FUJI for studying ice-navigation in Antarctic region. This paper discusses the ice-navigation and studies the strength of propeller-blade and propeller shaft of "Fuji" in ice.

Useful paper on a subject where there is a scarcity of information. The paper provides some information of shaft failures on Russian icebreaker and some comments on different approaches to shaft design.

REFERENCE: Sigg, 1972.

TITLE: The use of coarse pitches in marine propulsion gearing.

AUTHOR: Sigg, H.

SOURCE: 8th Round Table Conference on Marine Gearing, May 1972.

ABSTRACT:

Until some years ago when the power of the medium speed Diesel had not yet exceeded a few thousand HP, the reduction gears for multiple engine installations were usually very lightly loaded because of the relatively wide centre distances dictated by the engines if installed side by side. For this reason surface hardened gears were hardly ever used for such installations.

The much increased power of the new generation of medium speed diesel engines has drastically altered the situation from the gear maker's point of view. So drastically in fact, that gears with power division have even been suggested in order to maintain the minimum centre distance between two engines. It is shown that for the powers available today (27,000 HP/370 RPM) it is not necessary to go to the complication of the locked train gear. With surface hardened and ground pinions and ground gears made of high tensile steel (120 - 135 kp/mm^2) it is possible to solve the problem with straight forward parallel shaft gears.

The scope of this paper is to show that coarse pitches are best suited for Diesel propulsion gearing if materials of high hardness are used.

REFERENCE: Smith, 1983.

TITLE: An overview of steam developments.

AUTHOR: Smith, R.W.; Schubert, R.

SOURCE: Marine Propulsion, October 1983.

ABSTRACT:

One decade after the energy crisis of 1973, the struggle to control and reduce energy cost continues. Progress towards reduction in energy consumption and cost has been made through application of improved thermal cycles and alternate low cost fuels. This is no less true of the shipping industry than other sectors of power generation. Reduction of energy consumption in existing ships has been accomplished through fine tuning and modification of existing equipment. Introduction of new technology is aimed primarily at new ship construction.

Historically, the choice of fuel to be utilised has been determined based on availability, suitability, and economics. Since about 1940, petroleum based fuels were used almost exclusively in marine power plants. Fuel of good quality was available at an acceptable price. As a result, marine power plants were designed with simple steam cycles. Emphasis was directed toward reliable operation at full power with fuel economy and reduced power operation receiving only secondary consideration.

Rapid escalation of oil prices in the last decade has spurred the search for alternate low cost fuels and steam power plants provide flexibility in the type of fuel that can be burned. A study by the US National Academy of Science concluded that steam propulsion is the only marine prime mover capable of utilising any of the available or projected alternate fuels. Specifically, the steam power plant is the only prime mover capable of burning coal as a solid. The greater utilisation efficiency expected from the other less flexible prime movers is not sufficient to overcome the fuel cost advantage of the primary alternative to oil, coal. current trends indicate that residual oil prices will remain weak through to about 1986 and escalate rapidly in the late 1980's.

Paper provides a useful overview of present day status of steam turbine propulsion systems and highlights various options open to improve the efficiency of the system.

REFERENCE: Stiglitz, 1984.

TITLE: Static converters controlled propulsion systems for ice-going merchant ships.

AUTHOR: Stiglitz, J., Bilz, F.W.

SOURCE: Siemens Electric Limited.

ABSTRACT:

A review of the propulsion system requirements for an icebreaker is presented and the way various electrical propulsion systems can be tailored to meet their requirements, DC-DC, DC-AC and AC-FFC-AC systems are described and circuit diagrams presented of typical systems.

Paper is a useful overview of modern systems although does not provide any specific information, dealing with generalities.

/EFERENCE: Vassilopoulos, 1980.

TITLE: Longitudinal stiffness analyses for the propulsion shafting systems of the polar icebreaker.

AUTHOR: Vassilopoulos, L., Hamilton, F.

SOURCE: Naval Engineers Journal, 1980.

ABSTRACT:

During the first and second seasons of its deployment in the Antarctic region, the new United States Coast Guard Icebreaker, POLAR STAR, experienced longitudinal vibration problems in the center and wing shaft systems while breaking ice. To minimize and hopefully eliminate the vibratory responses, the USCG initiated several investigations, some of which will be treated in this paper.

One of the items under study concerned the axial stiffness of the shafting systems that is contributed by the thrust bearings, their housings and the foundations on which they rest. Aside from model test studies, numerical assessments were made of these stiffnesses using finite element methods and other techniques.

In all, three sets of thrust bearing foundations were analyzed in great detail. These include the original (as-built) foundations, a modified configuration that was subsequently adopted for the wing shafts of the POLAR STAR and POLAR SEA, and a reinforced configuration that represents an upper bound on the foundation stiffness that can be achieved without drastic changes in shafting system architecture.

The bulk of the paper deals with the development of the three finite element models that were exercised with the NASTRAN Computer Program to predict the stiffness of the three foundation designs. Various considerations that arise in model formulation are treated in some detail, especially the influence of chosen boundary conditions on the final answers. A simplified procedure is next outlined and used for estimating the stiffness of the thrust bearing itself. The estimate is based upon the use of simple structural models whose flexibilities are summed to get the net system flexibility.

The results of all the calculations are reviewed in light of the broader objectives of the overall program and recommendations are given for further investigations that will aid in the understanding of the Icebreaker vibration problems.

The paper is useful in that it highlights the difficulty of incorporating sufficently layer axial stiffness into the shafting system to ensure axial resources of the shaft systems are not excited in ice.

REFERENCE: Volcy, 1977.

TITLE: Deterioration of marine gear teeth cases encountered and solved.

AUTHOR: Volcy, G.

SOURCE: Bureau Veritas Technical Report, Paris, 1977.

ABSTRACT:

The authors discuss the design and performance of marine reduction gears in turbine and medium speed diesel installations from the operator's standpoint. The various criteria used by manufacturers in the design of marine gearing are examined and the relationship between these and Classifications Societies rules is discussed. Consideration is given to the various operating factors which can affect performance and comment is offered on why gearing sometimes falls short of expectations; examples from service experience are used for illustration. The part played by the operator in achieving and maintaining trouble-free operation and the more practical aspects of gear design and installation are examined. Special mention is made of investigational work and the techniques available. The importance of research laboratories in providing a link between design and practice is considered and it is emphasised how research and development can reduce uncertainties in gear design, thus increasing margins of safety. Finally, the authors look briefly into the future and attempt to define what the operator will expect from the manufacturer in terms of reliability and maintenance.

Actual problems with gears, accompanied by photographs, are discussed. Very useful examples of problems are provided.

REFERENCE: Wind, 1983.

TITLE: The dimensioning of high power propeller systems for Arctic icebreakers and icebreaking vessels.

AUTHOR: Wind, J.

SOURCE: 5th LIPS Propeller Symposium, May 1983.

ABSTRACT:

The massive growth of Arctic sea transport, planned for the coming years is associated with the application of unfamiliar propulsion equipment for icebreaking. The classical system with fixed pitch propellers, driven by electrically transmitted diesel - or steam - power, tends to make place for propulsion systems with new elements such as controllable pitch propellers and propeller nozzles.

The introduction of these new elements in very large dimensions, means that more and rather vulnerable parts will be exposed to heavy iceloads. The advantages of this kind of new equipment can only safely be utilized if its behaviour under such extreme loads can be sufficiently evaluated. Common knowledge at this stage is rather restricted, being based on the experience with a few number of installations in service. It is also clear that theoretical analysis can only partly answer the questions.

Since in the near future a considerable number of new installations for icebreaking will be put into operation, it is expected that the coming years will provide an unknown feedback of practical experience. A better understanding of the main influencing factors finally will result in strong changes in the concept of icebreaking propulsion equipment, extrapolated to large powers.

The paper describes the nature of iceloads and indicates methods to approximize the magnitude of ice impact on propeller blades and nozzles. The influence of power and propeller size is investigated. The resulting stresses are to be compared with allowable values both for a single static shock as well as dynamically in fatigue. Recommendations are given for the dimensioning of blade sections, the supporting points of nozzles and the way of determining their plate thickness. A comparison is made with the requirements of classification societies.

2.4.4 General Outfit and Auxiliarly Systems

GENERAL OUTFIT

Arctec Canada Limited
Arctic deployment of USCGC POLAR STAR, Winter 1982, Vol. IV - ice loads on steering gear systems. Report to TDC (TP4125E).

Arctec Canada Limited *
Study of rudders, rudder stocks, steering gears, manoeuvrability of Arctic class ships. Report to Canadian Coast Guard. 1984.

Arctec Canada Limited
Study of steering system components for Arctic class ships. Report to Canadian Coast Guard. 1979.

Atmospheric Environmental Service *
The ice accretion problem in Canada and waters related to service offshore energy and transportation.

Calabrese, S.J. *
Evaluation of two icebreaker hull coatings for Arctic petro carrier project. Report prepared for Melville Shipping Ltd. 1980.

Calabrese, S.J. *
Low friction coatings for icebreakers. National Technical Information Service, RPI report for USCG. 1974.

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Frictional characteristics of materials sliding against ice. American Society of Lubrication Engineers. 1979.

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Low friction coatings for icebreakers: Phase II, Parts I and II - laboratory and field tests. Rensselaer Polytechnic Institute. 1976.

Churcher, A.; Kolomocjev, A.; Hubbard, G.
Design of the ROBERT LEMEUR icebreaking supply ship. Marine Technology, Vol. 21, No. 2. 1984.

Cuthbert, D.R.; Seidl, L.H.
Mathematical analysis of ship mooring systems and comparisons with hydraulic scale model investigations. POAC. 1977.

Gauthier; Page; Wyld *
Study of ship ballasting and fluid systems for ice navigation. Report to TDC. 1983.

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Hull coatings for ice trading. Shipping World and Shipbuilding. 1982.

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Design of steering gears, rudders, rudderstocks, and propeller protection for Canadian Arctic vessels. Marine Technology, July. 1982.

Levelton, D.H.
Study on hull corrosion and coatings. Report for TDC. 1985.

Loset, S.
Investigation and research on anti-icing and de-icing devices for marine application. Norwegian Marine Technology Research Institute.

Lumsden, R.W. *
Study of mooring rope materials for Arctic LNG carriers including behavior of rope at low temperature. Arctic Pilot Project. 1980.

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Melville Shipping Ltd. *
Marine crew survival in the Arctic. Report for Transport Canada - TP7348E. 1986.

Melville Shipping Ltd. *
Special requirements of shipboard firefighting systems used in cold temperatures. Report to Canadian Coast Guard. 1985.

Melville Shipping Ltd. *
Lifesaving equipment for Arctic ships. Report for Transport Canada - TP6903E. 1984a.

Melville Shipping Ltd. *
Crew accommodation on Arctic class ships. Report to Canadian Coastguard. 1984b.

Melville Shipping Ltd.
Personnel considerations in the safe operation of ships transitting the Canadian Arctic. Report to Canadian Coast Guard. 1984.

Menon, B.; Noble, P. *
Ice impact loads on steering system components of Arctic class ships. POAC. 1979.

Minsk, L.D.
Assessment of ice accretion on offshore structures. CRREL. 1977.

National Fire Protection Association
Fire extinguishing equipment standards.

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Any old paint - not likely. August. 1985.

Oka, M.; Kobayashi, E.T.M. *
Study on tank heating in Arctic merchant vessels. Kawaski Heavy Industries.

Peravaimo, M. *
Ships winches under Arctic conditions. NSTB '85 meeting, Lyngby, Denmark. 1985.

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M.V. ARCTIC - operational evaluation. Report to TDC. 1981.

Taylor, H.D.; Purcill, P.M.
Problems of fire control on board ships. Institute of Marine Engineers.

Trident Engineering Associates
Maritime LNG manual. U.S. Department of Commerce.

REFERENCE: Arctec Canada Limited, 1984.

TITLE: Study of rudders, rudder stocks, steering gears
and manoeuvrability of Arctic class ships.

AUTHOR: Arctec Canada Limited

SOURCE: Transport Canada

ABSTRACT:

This report forms part of the present efforts to obtain the state-of-the-art in rudder and steering gear design practice:

Task 1: Review current status of design, construction and operations of rudders and steering gears onboard vessels operating in in an Arctic Environment.

Task 2: Literature review - compile and collate data.

Task 3: Development of scenarios.

Task 4: Applicability of data to scenarios.

Task 5: Development of guidelines for preliminary standards.

Task 6: Identification of additional data required and methods of achieving them.

REFERENCE: Atmospheric Environment Service, 1985.

TITLE: The ice accretion problem in Canadian waters related to offshore energy and transportation.

AUTHOR: Brown, R.D., Roebber, P.

SOURCE: Atmospheric Environment Service (unpublished manuscript).

ABSTRACT:

The objectives of this study were to:

1. Delineate the scope of the icing problem in Canadian waters identifying offshore industry needs for icing-related information

2. Compile and analyse a database of vessel icing information from Canadian waters.

The report includes a general discussion on icing of offshore structures and aircraft, a discussion of the characteristics of icing in Canadian waters. Problem areas in the modelling of ice accretion on ships and structures are identified and anti and de-icing strategies discussed. The results of consultations with the offshore oil industry and regulatory bodies are also included.

This is a comprehensive report which documents the ice accretion season in Canadian waters, the causes, the geographical distribution of icing reports and icing severity. A section of the report deals with these features of icing as they apply to eastern Canada. The report describes the physics of ice accretion and reviews modelling procedures. Brief descriptions are given of precautionary measures which can be taken and identifies priority areas for further work. It also permits the problems associated with data collection.

REFERENCE: Calabrese, 1974.

TITLE: Low friction coatings for icebreakers.

AUTHOR: Calabrese, S.J.

SOURCE: National Technical Information Service , June 1974, RPI Report for USCG.

ABSTRACT:

Part I of the first phase of development of low friction coatings for icebreakers involved in evaluation of State-of-the-Art coatings available from industry. Laboratory simulation tests were conducted to determine materials' ability to withstand ice impact forces, abrasion resistance and scratch resistance as well as quantifying various frictional properties of the materials with varying ice properties. Several coatings were selected out of over 100 samples tested for application icebreakers.

Part II of Phase I the coatings selected in Part I were applied to small icebreakers for initial full scale evaluation. Tests described and results discussed.

REFERENCE: Calabrese, 1980.

TITLE: Evaluation of two icebreaker hull coatings for Arctic Petro Carrier project.

AUTHOR: Calabrese, S.J.

SOURCE: Report prepared for Melville Shipping Ltd., 1980.

ABSTRACT:

A program was devised to establish the various characteristics of the two most successfully used icebreaker hull coatings. Both coatings have been used by the U.S. Coast Guard as well as other owners of ice transiting ships in Canada and Europe. The purpose of the program was to determine if the coatings would have the ability to resist ice abrasion during service and continually protect the hull of an LNG tanker which was being designed by Melville Shipping Ltd.

REFERENCE: Gauthier, 1983.

TITLE: Study of ship ballasting and fluid systems for ice navigation.

AUTHOR: Gauthier, Page, Wyld

SOURCE: Transportation Development Centre.

ABSTRACT:

This report describes various aspects of a study to identify and analyse the problems of freezing of ship ballast systems in cold climatic conditions and to propose solutions for the purpose of providing the marine industry with criteria and guidelines for designing, constructing and operating efficient ballast systems. Areas of research and development are identified.

Interviews conducted with designers, shipbuilders and operators and questionnaire replies received from many interested persons proved valuable in confirming the study members own knowledge of the matter. This allowed the coverage of all geographical areas in which occur the freezing conditions, i.e. the Beaufort Sea, eastern Arctic, eastern Seaboard, St. Lawrence River and Great Lakes. The government and private sectors were included.

The study deals with tank and piping systems, valves and other components or products, ice ingestion of sea water inlets and it identifies areas of research and development.

The identification and description of the problems are followed by suggestions of solutions applicable to different types of ships, climatic exposure and voyage patterns. Many problems are minor, only a few are of large magnitude. The solutions in existing vessels pertain to operating procedures and partial design changes to systems and products. New designs should consider tank and sea inlet structural changes, utilization of waste heat, supply of heat and improved products design.

REFERENCE: Jorgensen, 1982.

TITLE: Influence of the ice accretion on activity in the northern part of the Norwegian Continental Shelf.

AUTHOR: Jorgensen, T.

SOURCE: Ship Research Institute of Norway.

ABSTRACT:

The report is an approach to the problems of icing in offshore activity based on a literature survey on icing at sea. The various meteorological and vessel and structure-dependent factors of significance to the phenomenon of icing, and the hazards of icing on vessels, platforms and helicopters are discussed.

The work carried out to improve the safety by introducing minimum ice loads, and the probabilities of icing dependent on meteorological conditions and various waters are described.

Actions against icing as icing warnings, design and handling of vessels and platforms are discussed, and various mechanical, thermal and chemical de-icing and anti-icing methods are described.

REFERENCE: Lumsden, 1980.

TITLE: Study of mooring rope materials for Arctic LNG carriers including behaviour of rope at low temperatures.

AUTHOR: Lumsden, R.

SOURCE: Arctic Pilot Project, 1980.

ABSTRACT:

This report makes an attempt to bring together available information on the performance and properties of various ropes at low ambinet temperatures. Important conclusions are presented in relation to:

a) preferred synthetic mooring ropes,
b) usefulness of wire ropes,
c) mooring system design,
d) mooring procedures.

REFERENCE: Korbijn, 1981.

TITLE: Iceloads on rudders and screws.

AUTHOR: Korbijan, F., Hysing, T.

SOURCE: Marine Structures and Ships in Ice (1981).

ABSTRACT:

A review of the rudder stock strength requirements of the DNV and USSR regulations for ice-transitting vessels has been made. It was found that, in these rules, the global ice loads have been taken as two to three times the corresponding hydrodynamic rudder loads and the ice torques as five to seven times the hydrodynamic moments. The authors recommended, in view of the large number of damages that have occurred to rudders on ships operating in ice, even higher ice magnification factors may be used for design of the structural parts of the rudder system.

REFERENCE: Makkonen, 1984.

TITLE: Atmospheric icing on sea structures.

AUTHOR: Makkonen, L.

SOURCE: CRREL, 1984.

ABSTRACT:

Atmospheric icing (icing due to fog, precipitation and water vapor in air) as a physical process and the problems it causes for ships and stationary offshore structures are reviewed. Estimation of the probability and severity of atmospheric icing based on climatological and geographical factors is discussed, and theoretical methods for calculating the intensity of atmospheric icing at sea are suggested. Existing data on the dependence of the atmospheric icing rate and the properties of the accreted ice on the meteorological conditions are analyzed. The methods of measuring the icing rate and ice prevention methods are discussed.

REFERENCE: Melville, 1984.

TITLE: Lifesaving Equipment for Arctic ships.

AUTHOR: Holburn, J.G., Thompson, E.W.

SOURCE: Transport Canada (TP-6903-E).

ABSTRACT:

The Lifesaving Equipment Regulations of the Canada Shipping Act do not distinguish between the lifesaving equipment to be carried by vessels which operate in the Arctic from that required to be carried by similar vessels operating in temperate waters. The Canadian Regulations are not unique in this respect, as the Regulations of the I.M.O. Convention on Safety of Life at Sea (1974) and the recent amendments to Chapter III and the Regulations of the principal signators of the Convention do not treat ships which operate in the Arctic as a separate class.

The report discusses the implications of the current regulations and itemizes the deficiencies. Recommendations are made for changes to the regulations and new equipment is identified.

This comprehensive report is of primary concern to those involved in safety of personnel in Arctic ships. The report investigates the suitability of lifesaving equipment carried by ships trading in the Arctic. Deficiencies and shortcomings of the equipment are identified and solutions or alternatives are proposed. Of special interest is the section on additional equipment and survival craft.

REFERENCE: Melville Shipping Ltd., 1984b.

TITLE: Crew accommodation on Arctic class ships.

AUTHOR: Thompson, E.W.

SOURCE: Transport Canada, 1984.

ABSTRACT:

This study undertakes a survey of the existing regulations for ship accommodation, investigates the standards of accommodation presently provided onboard vessels operating in the Arctic, consults with owners and crews to ascertain their perception of accommodation standards and to develop scenarios for the future.

Many of the conclusions of this study tend to be subjective in nature. Relevant Canadian and selected foreign marine regulations have been researched and compared. Views have been canvassed from ship operators, designers and crews and their responses recorded. In addition the medical profession has been consulted on those aspects of the study which they are best qualified to address.

REFERENCE: Melville, 1985.

TITLE: Special requirements for shipboard firefighting systems used in cold temperatures.

AUTHOR: Holburn, J.

SOURCE: Transport Canada (TP-6225-E).

ABSTRACT:

This report presents the results of a study to determine the effectiveness and suitability of shipboard fire extinguishing agents, systems and appliances, for use in very cold temperatures.

This report documents the environmental conditions which affect firefighting capability and identifies the firefighting problems which can arise. Procedures adopted by land based fire services to overcome cold temperature firefighting problems are included as are the protective measures adopted by shipowners and shipbuilders.

The firefighting and equipment standards and regulations for ships, offshore structures and helicopter decks of a number of national administrations are examined, and their cold temperature references compared.

A guideline specification for shipboard firefighting systems and equipment for cold temperature operations is presented, as are crew training requirements.

Based upon the study findings, recommendations are made for regulatory changes and proposals are put forward for further research required to resolve outstanding problems.

This exhaustive report is of primary concern to both regulatory bodies and operators of Arctic vessels. Investigations are made into current regulatory standards and many recommendations are made for improvements. The environmental conditions are well documented and problem areas identified.

REFERENCE: Melville, 1986.

TITLE: Marine crew survival in the Arctic.

AUTHOR: Holburn, J.G., Dick, R.A.

SOURCE: Transport Canada (TP-7348-E).

ABSTRACT:

This report examines the requirements of the Lifesaving Equipment Regulations of the Canada Shipping Act with a view to their applicability to Arctic ship operations with respect to survival equipment and supplies as distinct from appliances.

The report describes the potential ship abandonment scenarios in the Canadian Arctic and the consequent threats to crew survival and concludes that equipment required by the regulations is inadequate.

An evaluation is made of currently available survival equipment and suppliers, and equipment under development is identified. Crew survival equipment which should be carried by ships which operate in Arctic waters is recommended, together with tests which should be initiated. In addition, deficiencies in crew survival training (M.E.D.) are presented and suggestions are made on how they may be remedied.

This exhaustive report provides a good current overview. It is of special interest to those concerned with ship operations in Arctic waters. Of special interest is the concept for the equipment to be carried by Arctic class vessels. It is however, a paper study and should be read with that in mind.

REFERENCE: Menon, 1979.

TITLE: Ice impact loads on steering system components of Arctic Class ships.

AUTHOR: Menon, B., Noble, P.

SOURCE: POAC, 1979.

ABSTRACT:

A study of the steering system components of Arctic class ships is conducted. The study is aimed at developing preliminary design interior for rudder stocks, pintler and steering gears. Steering system damage statistics indicated that the most common case of steering system damage is the tortional failure of the rudder stock. A mathematical model of ice impact process is developed which predicts the ice torque on the rudder stock and the response of the steering gear as a function of time. Typical examples of the simulation are illustrated and compared with full scale measurements. The reaction times of conventional hydraulic steering gears are found to be longer than the typical duration of ice impacts, thus do not act as a efficient shock absorbing device. It is also concluded that the nominal operating in thickness specified for icegoing ships do not represent sufficiently the design conditions for steering components.

REFERENCE: Oka, 1985.

TITLE: Study on tank heating in Arctic merchant vessels.

AUTHOR: Oka, M., et al

SOURCE: Translation from KHI Technical Report Vol. 87, 1985.

ABSTRACT:

Freezing of sea water in the ballast tank must be prevented in the merchant vessels which navigate the Arctic Ocean in winter. Therefore, heating coils need to be arranged and to heat the tank. For this purpose, it is necessary to comprehend the freezing phenomena, natural convection, and temperature distribution in the ballast tank.

The authors have established a tank heating analysis method which is applicable to the design of a rational heating coil arrangement. This paper describes the analysis method and comparison of model test data with analysis data, and shows an example of application of the method to an actual vessel.

REFERENCE: Peravaimo, 1985.

TITLE: Ships winches under Arctic conditions.

AUTHOR: Peravaimo, M.

SOURCE: NSTM 85 meeting, Lyngby, Denmark, October 1985.

ABSTRACT:

The paper discusses the problems associated with Arctic temperatures on machinery parts in exposed deck machinery and offers some solutions and guidelines for manufacture.

The paper recommends the use of cold temperature steel in the manufacture of deck equipment due to the low ambient temperatures and also to be aware of problems with seals and gaskets, bearing clearances, the viscosity of greases and oils and the start-up temperatures of internal machinery.

Heating of the oils/lubricants can help allieviate this along with proper and careful start up procedures ensuring all internals are heated sufficiently. Electric motors should be cold resistant and have standstill heating included in their design.

REFERENCE: Stallabrass, 1980.

TITLE: Trawler icing: a compilation of work done.

AUTHOR: Stallabrass, J.

SOURCE: National Research Council of Canada, 1980.

ABSTRACT:

This report collates and reviews the results of an eleven-year project on the icing of fishing trawlers.

Initially the factors causing the icing of ships at sea are presented and some aspects of the physics of the icing process are discussed.

Some simple icing tests on cylinders of various diameters are described. These were made in an icing wind tunnel and demonstrated the effects of air temperature and cylinder size on the resulting ice formations. Later, a number of possible methods for reducing the icing hazard were tested in the wind tunnel and at an outdoor test rig. Of the methods tested the most effective was an inflatable rubber de-icing blanket.

Throughout the project, icing report forms were distributed to vessels operating out of Canadian east coast ports. The data obtained by this means has helped to establish the types of weather systems responsible for icing conditions, the geographical extent of the occurrence of icing, and statistics on the severity of icing encounters in the study area.

Appendices present simplified formulae for the droplet collection efficiency of cylinders and rectangular bodies, the derivation of an analytical expression for the rate of ice build-up on fishing trawlers, and a bibliography of ship icing.

The ice formation process is cleanly described and formulae for calculating the rate of icing on an obstacle are presented. Icing wind tunnel tests were carried out on test cylinders to ascertain icing rates but they are no more than a rough guide since the relationship to actual rates of icing at sea is unknown. There is great uncertainty however in predicting icing rates and most formulas used are impirical. Statistics derived from a seven year ship reporting programme show many inconsistencies due to subjective judgements of shipboard personnel. Methods of reducing the ice hazard are described but are based only on laboratory tests.

REFERENCE: Stockdale, 1981.

TITLE: M.V. ARCTIC - operational evaluation.

AUTHOR: Stockdale, A.

SOURCE: Transport Canada, Transportation Development Centre.

ABSTRACT:

This is a report of the experience gained between 1978 and 1980 during the operation of the M.V. ARCTIC as a Class 2 Arctic vessel and as a world trader. Operational performance of the hull and ship system in cold conditions and in general trade is recorded following discussions with ship operators, and a review of available office records. The capability of the vessel to manoeuvre in ice is reviewed and summarized following a detailed consideration of the available reports. Various methods of navigating in ice are described and discussed in relation to the vessel's demonstrated response characteristics. Incidents involving hull damage due to ice encounter are described, as well as the extent of structural damage involved. Although tnis report is primarily intended to present the ship's performance record in ice and cold region operation, other factors concerning the vessel's cargo carrying capability and propulsion and auxiliary machinery reliability are discussed. Several recommended design improvements or improved operating procedures are offered to overcome the difficulties experienced under cold conditions, or generally, in such ship activities as ballasting, cargo handling and storage, and in design features such as wheelhouse layout and navigating equipment selection.

2.5 Miscellaneous

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